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UNIVERSITY OF NEW MEXICO
ALBUQUERQUE

ENGINEERING EXPERIMENT STATION

Technical Report EE-86

SURVEY OF PAPERS ON TROPOSPHERIC REFRACTION

by
Richard O. Gilmer
Wallis R. Cramond
Marvin R. Byrd

February, 1963

UNM

This work performed for
White Sands Missie Range under
Contract DA-29-040-ORD-1238

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ABSTRACT

Five hundred eighteen papers concerning tropospheric refraction and some closely related topics are referenced in this report. Of these, one hundred ninety-one are abstracted. Neither refractivity measuring equipment nor other atmospheric effects in the troposphere are specifically covered. Cross listings of authors and ASTIA numbers are given. Enough information is given on each listing such that it could be obtained.

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SECTION I
INTRODUCTION

The purpose of this report is to reference in one place as many of the papers written on the subject of tropospheric refraction as possible. There are doubtless omissions and perhaps errors also. Nevertheless, it is hoped that enough information is given for each entry so that an interested person can obtain the reference. Many of the articles were included as a result of bibliographies of reports in the possession of this group.

Under the abstracted report section are all those articles located by this group so that they could be abstracted. Many articles had abstracts that were used in full or in part, while abstracts were written on others. Often there are more topics covered in a report than can be conveniently referenced in an abstract. We acknowledge that this listing is only a guide for someone interested in tropospheric refraction and it is in no way implied that the survey is complete or entirely accurate.

We shall appreciate knowing of any errors or omissions that the readers of this report may find. Comments, corrections, and inquiries should be addressed to the Microwave Laboratory, Department of Electrical Engineering, The University of New Mexico.

No abstracts are given for papers published in periodicals since such periodicals are generally readily available. Whenever there were articles found in periodicals covering the same material published in a report, these entries are cross-referenced.

Several abbreviations were used and are included here as a formality and for those who may not be entirely familiar with them.

AWS	-	Air Weather Service
EERL	-	Electrical Engineering Research Lab.
UNM	-	University of New Mexico
MIT	-	Massachusetts Institute of Technology
AFB	-	Air Force Base
AFMTC	-	Air Force Missile Test Center
ARDC	-	Air Research and Development Command
WADC	-	Wright Air Development Center
ASTIA	-	Armed Services Technical Information Agency
NBS	-	National Bureau of Standards
U.S.N.	-	U. S. Navy
NRL	-	Naval Research Lab.
LMSD	-	Lockheed Missile Systems Division
URSI	-	International Scientific Radio Union
WSMR	-	White Sands Missile Range
WSPG	-	White Sands Proving Grounds
IRIG	-	Inter Range Instrumentation Group
WSSA	-	White Sands Signal Corps Agency
NASA	-	National Aeronautics & Space Administration
RADC	-	Rome Air Development Center

Emphasis was placed on tropospheric refraction, consequently other atmospheric effects are included only when they appear with refraction. No ionospheric refraction papers are included. Further, reports on electronic equipment, radar, or index of refraction measuring devices were not listed except if they contained observed refraction data or analysis techniques.

Of the total entries, 191 were abstracted reports, 138 were non-abstracted reports, and 189 were articles appearing in periodicals. Cross listings of authors and ASTIA numbers were compiled with the appropriate report numbers to aid the reader. All available reference sources were checked up to the end of 1961 although there are surely several recent papers that were overlooked.

The authors wish to acknowledge the guidance and supervision on this task given by Dr. Donald C. Thorn. This work was supported by the Missile Geophysics Division of the Army Signal Corps at White Sands Missile Range.

SECTION II

LIST OF AUTHORS

SECTION III

LIST OF ASTIA NUMBERS

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UNM REPORTS

SECTION IV

ABSTRACTED REPORTS

A1 Accuracies of Radiosonde Data
Unknown author
AWS Tech. Rept. No. 105-133 HQ AWS MATS USAF
Sep 55

The question of radiosonde accuracies is one which is often asked but seldom answered to complete satisfaction. While the reasons for this are many and complex, the basic difficulty lies in the fact that there is no method by which the absolute accuracy of data from a radiosonde can be directly determined once the instrument leaves the ground.
Instruments for measuring meteorological elements on or near the ground maybe compared with precision instruments of known accuracy and the accuracy of measurement thereby determined. Radiosondes are also checked in this manner. Unfortunately, however, the mass of data obtained over a period of years from radiosondes shows rather conclusively that accuracies under such conditions are not maintained in actual flight. The users of upper air data nevertheless, have a continuing need for information on the accuracy they can expect from in-flight data; and various studies, reports, investigations, and analyses of observational data have been made in an attempt to provide results of these investigations are not in complete agreement; one will find estimates of the "error" in temperature, for example, from a few tenths degrees. One reason for this variation is that the several investigators in different ways. It is the purpose of this paper to discuss the definitions of "accuracy" and to compare and evaluate the results of available studies and reports on accuracies of radiosonde data. These results will provide information to forecasters, analysts, and other users of upper-air data which may be used in determining the limits within which data available to them are valid.

A2 Airborne Measurements of Atmospheric Refractive Index Micro-Variations up to 20,000 ft. MSL over Southeastern Colorado.
Crain, C. M.
EERL Rept. No. 5-11
Dec 55

This report gives the results of measurements of micro-variations in the index of refraction of the atmosphere made over southeastern Colorado in Feb. 1954, Aug. 1954, and March 1955. Data were obtained by the Propagation Section of the Wright Air Development Center using sensitive scale microwave refractometers on a photographic recorder having a time constant of about .008 second and an Esterline-Angus recorder having a time constant of about 0.2 second. At the highest rate of film speed used for the March 1955 measurements, i.e. 6"/sec, it was possible to accurately resolve refractive index variations occurring over distances as small as about 2 ft. at plane speeds of 250 ft/sec. Variations occurring over distances less than about 2 feet were recorded with reduced amplitudes. Calculations of the average of the parameter $\Delta N^2/1$ are made from the measurements and compared with other predicted average values obtained from the application of scattering theory to measured radio data on distances beyond the horizon.

A3 Amplitude and Phase Difference Fluctuations of 8.6 Millimeter and 3.2 Centimeter Radio Waves on Line of Sight Paths.
Tolbert, C. W.; Fannin, B. M.; Straiton, A. W.
EERL Rept. No. 78
Mar 56

This report presents data on 8.6 MM wavelength of phase difference fluctuations on a ten mile path in Colorado between Pikes Peak and the Garden of the Gods and of amplitude fluctuations on this path and on a sixty mile path between Pikes Peak and Mount Evans. The millimeter data are compared with similar data taken using a wavelength of 3.2 cm.

A4 An Analog Computer for Calculating Atmospheric Density and Refractive Index
Cramond, Wallis R.; Thorn, Donald C.
UNM Exp. Sta. EE58
Jul 61 AD 287 233

This report explains the design and operation of a simple analog computer to solve for refractivity and density in the atmosphere. The equation for density is developed and appropriate scale changes are included to cover most all meteorological situations. Special attention is given to the design of a nonlinear potentiometer. Accuracy and tolerance requirements are discussed. Sufficient information including circuit diagrams is presented from which similar units could be built.

A5 An Analysis of Angular Accuracies from Radar Measurements
Manasse, Roger
MIT Lincoln Lab. Ground Rept. 32-24
Dec 55 AD 236 166

With the aid of certain simplifying assumptions, a theoretical formula for angular accuracy of a radar measurement is derived. For reasonable signal detectability the accuracy proves to be a small fraction of the antenna beamwidth. The optimum procedure requires a large number of separate receivers to process the received energy. An approximate method of processing received angular information which compares the output from only two receivers, as in a monopulse technique, results in an accuracy which compares favorably with the optimum.

A6 An Analysis of Atmosphere Refractive Index Fluctuation as Recorded by An Airborne Microwave Refractometer
VonRosenberg, Charles E.
Master's Thesis, U. of Texas
Jan 53

Several attempts have been made to explain theoretically the reception of radio signals for beyond the horizon in the frequency range where ionospheric reflection is not a significant factor. One of these is the theory of scattering by irregularities or fluctuations of the atmospheric refractive index. There has been a need for experimental information on the magnitude and linear dimensions of such fluctuations in order to evaluate the contribution from this phenomenon to the received signal strength. This report presents a statistical analysis of the fluctuations indicated by some of the first measurements of atmospheric index of refraction made with an air-borne microwave refractometer.

A7 An Analysis of Atmospheric Refraction
Faulds, A. H.; Brock, R. H.
Syracuse Univ. Res. Institute
Mar 60 AD 272 586

An optical ray which travels from a point on the surface of the earth to a point in space is continuously refracted as it passes through an atmosphere of continuously decreasing density. Atmospheric refraction thus bends optical rays to curvilinear form and this effect must be considered in aerial photogrammetry when the utmost accuracy is desired.

A8 An Analysis of Radiosonde Effects on the Measured Frequency of Occurrences of Ducting Layers.
Wagner, N. K.
EERL 6-31
Dec 59 See Periodical P7 AD 229 858

The influence and importance of radiosonde sensing element time lag, data transmission techniques, and significant level selection criteria on the resulting computed index of refraction profile are discussed. Time lag is found to be the most important single effect with data transmission techniques next in importance. Significant level criteria have a very small effect on ducting layer detection, and when considered in combination with time lag and data transmission techniques are negligible. The quantitative importance of these radiosonde effects on ducting layer detection for the Southern California costal region is determined by employing a refractometer profile data sample along with known and assumed characteristics for the radiosonde. A comparison is also made between layer frequency of occurrence statistics obtained from refractometer and radiosonde data for this geographical area.

A9 Analysis of Refractive Index Errors
Epstein, R. A.
AF Tech. Rept. No. 2 AFMTC Patrick AFB
Mar 51

In seeking an accurate determination of the velocity of propagation of electromagnetic waves through the atmosphere, a precise knowledge of the index of refraction n is requisite. Thus the

effect of meteorological factors upon the refracture index is of considerable importance, especially for geodetic surveying by Shoran and for electronic precision tracking of guided missiles.
It is therefore of considerable interest to examine the empirical constants and the meteorological factors that enter into the formula for the atmospheric index of refraction, and to determine their individual and total RMS contributions to the error in the refractive index.
These results are then compared with the direct measurement of the atmospheric dielectric constant with more complex equipment.

A10 An Analysis of the Time & Space Scale Problems in Radio Meteorology
Colin, L.; Engleman, A.
Tech. Rept. No. RADC-TN-57-394 RADC, Griffiss AFB, N.Y.
Dec 57 AD 131 392

Rawinsonde data from three experimental range stations and five regularly reporting stations were collected during the summer of 1956. Flat earth approximations of the elevation angle and range errors were derived from more precise spherical earth equations. It is concluded from the space scale analysis that the magnitude of the surface index variations makes the application of the total elevation angle error of one station to that of another prohibitive. Application of the integrated index at the longest separations still does not violate the basic system requirement of one-tenth of a milliradian. A similar time analysis indicates that after a time interval of three hours has elapsed, little can be gained from the application of the integrated index before another 24 hour period. Preliminary data indicate that the total error may be applied for time intervals less than three hours.

A11 An Analysis of Tropospheric Ionospheric and Extra-Terrestrial Effects on VHF and UHF Propagation
Millman, G. H.
GE Co. Electronics Div.
Oct 56 AD 137 969

Analysis of the effects of the atmosphere and extraterrestrial noise sources on the propagation of VHF and UHF waves indicated that the refraction and time delay effects in the troposphere are independent of frequency but are a direct function of the amount of relative humidity in the air. Ionospheric refraction and time delay errors are inversely proportional to the square of the frequency and are a maximum during the daytime. The Doppler frequency error in the troposphere is directly proportional to frequency. For propagation at 100 mc and at a 5^{o} elevation angle, the maximum error is 10.5 c. Under similar operating conditions and for daytime and nighttime ionospheric propagation, the maximum Doppler frequency error is about 66 and 22.5 c, respectively, and is inversely proportional to frequency. Ionospheric polarization shift is inversely proportional to the square of frequency. The polarization change during the daytime is about 3.5 times greater than during the nighttime. Ionospheric attenuation is inversely proportional to the square of frequency. Daytime absorption is 18 times greater than the nighttime effect. The maximum total daytime attenuation at 100 mc appears to be of the order of 1.28 db. The theoretical total radiation from the quiet sun, in the RF spectrum, is directly proportional to the frequency raised to about the 0.755 power. The total flux density emanating from the 2 major discrete radio stars, Cassiopeia and Cygnus, is inversely proportional to the frequency raised to the 0.81 power.

A12 Analysis of Wave Equations for Radio Propagation in Over-Water Ducts.
Pierson, A. L., III
Master's Thesis U. of Texas
May 49

Usually M curves for over-water ducts are calculated from meteorological measurements of humidity, temperature, and barometric pressure. With the meteorological M curves known, the wave equation of mode propagation may be solved for the radio quantities of signal strength and phase angle. During the summer of 1947, meteorological and radio observations were made over Gulf Coast Waters by the University of Texas. From the radio measurements, it is possible to calculate meteorological curves which compare favorably with the observed average meteorological curve. Hence, it can be seen that it is possible to calculate radio curves from meteorological observations or meteorological curves from radio observations. For the average meteorological curves obtained by the University of Texas during 1947, it was found that the usual methods of solution of the wave equation do not generally apply. Even though the usual methods of solution do not apply, it is possible to obtain approximate solutions.

A13 Angle of Arrival Aspects of Radio Meteorology
Gordon, W. E.; Waterman, A. T.
U. of Texas EERL-1
Mar 46

The radio and meteorological measurements were taken in northern New Jersey during August and September 1945. Facilities for measuring the angle-of-arrival of incoming radio waves at both 3.25 and 1.25 cm. were established on a transmission path from Deal to Beer's Hill. Signal level records on these same two frequencies were also obtained on this path as well as on one from New York City to Mt. Neshanic. Low level meteorological soundings, involving measurement of air temperature and humidity at specified elevations, were made at Holmdel, Oakhurst, and Hadley airport. Wind speed records at these three locations and general synoptic weather charts supplemented the sounding data.

Analysis of the results indicated that approximately standard atmospheric and propagation conditions prevailed a large part of the time. In the period covered by the angle-of-arrival measurements, only two occasions, both at night, showed angles differing appreciably from that of a standard ray. On each of these occasions, the records indicated that rays were arriving at angles considerably above standard, the maximum observed being 0.70 degrees and that two or more rays were at times arriving simultaneously at different angles, the maximum number being four. Both of these extremes were on K-band. The two nights in question were characterized by atmospheric stratifications in which the vertical distribution of refractive index indicated extreme conditions of superrefraction. Rapid fluctuations of both radio and meteorological quantities on these two nights and the limited range of variations on all other occasions hindered the confirmation of a precise relationship between angle-of-arrival and vertical refractive index gradient, though the general association was apparent. Signal level and fading characterisitcs appeared to be related to both wind speeds and vertical index gradients, some of the principle associations being (a) that of moderate and severe fading at X-band on both paths to strong refracting conditions, (b) that of low signal level and marked fading range at both frequencies on the Neshanic path to calm wind conditions (owing to local differences this was not apparent on the Beer's Hill path) and (c) that of low signal level at K-band (and not at X-band) to high humidity conditions, an indication of the attenuation due to water vapor and possibly water droplets.

A14 An Approach to Azimuth Angle Refraction Corrections
Cramond, W. R.; Thorn, D. C.
UNM Tech. Rept. EE72
Apr 62 AD 287 230

A model of the lower atmosphere is developed using combinations of plane surfaces. This model is applied to the refraction technique developed in UNM EE43 in order to arrive at a simple azimuth angle correction. Given three vertical profiles of refractivity and the incorrected aximuth angle, an angle correction can be found for the basic case. Actual data is shown toward supporting the necessity of considering azimuth angle bending.

A15 Atmospheric Effects on Ground-to-Air Microwave Radio Propagation
Taylor, P. B.
WADC Tech. Rept. 56-315
Aug 56 AD 97 165

The effects on microwave propagation produced by superstandard refractive layers in the atmosphere are studied by ray tracing methods. It is shown that these layers are not strictly level but tilted or wavy. This tilt is an essential element in the mechanism whereby these layers may bring about the anomalies of ground-to-air propagation which are observed. When the layer is inclined so that a ray passes tangent to the layer, the distortion of the ray pattern is at its worst. The distortion may show as irregularities of signal strength (radio holes), or as irregularities in apparent target position. A set of available ground-based radar observations of an airborne target is analyzed and many anomalies (sharp fading) are found at elevation angles below 1 degree. Superstandard refractive layers simultaneously observed are shown to account adequately for the effects observed.

A16 Atmospheric Effects on Microwave Radio Propagation
Taylor, Paul B.
WADC Tech. Rept. 54-549
Dec 54 AD 64 927

This report traces the historical development of the thesis that irregularities in the propagation of microwaves are largely to be accounted for by irregularities in the distribution of water vapor in the atmosphere through the effect of the water vapor on the index of refraction. Experimental studies of the refractive properties of atmospheres by means of the airborne radio refractometer are fully described. A mathematical theory by which the characteristics of the radio propagation may be derived from a given distribution of refractive index in an atmosphere is developed. This theory is then applied to a variety of cases in which both the atmospheric refraction and the propagation have been simultaneously observed, and it is shown that the propagation derived from the refraction agrees with that directly observed. The agreement is offered as justification for a new procedure for investigation of radio propagation through an atmosphere: to observe the refractive data only, without direct observation of radio signals at all, and to determine the propagation characteristics solely by means of the refractive data. The report concludes with a clinching example of this procedure.

A17 Atmospheric Limitations on Electronic Distance Measuring Equipment
Thompson, M. C.; Janes, H. B.; Freethey, F. E.
NBS Rept. 6060
May 59

The effect of atmospheric turbulence on distance measurements using radio or radar signals is analyzed. From experimental data it is shown that refractivity corrections to a homogeneous atmosphere improve the standard deviation of such distance measurements over a four day experimental period. Also the effect of a running average is to decrease its standard deviation for larger running averages.

A18 Atmospheric Refraction Error in Radar Elevation Angles
Moler, W. F.; Gossard, E. E.
USN Elec. Lab. No. 795
Jul 57 AD 205 222

It was found that the surface value of atmospheric refractive index can be used to predict angular error for targets above 105 feet for ground sited radars.
The frequency distribution of angular error is shown to be a function of season and target height for selected stations along the northern border of the U. S. and near the Arctic Circle. Duirnal and short period changes of surface refractive index in the Arctic are shown to be small. The large scale changes are found to occur on a synoptic scale and are therefore capable of being forecast.

A19 Atmospheric Refraction Over Water
Yates, H. W.
Naval Research Lab.
Jul 56 AD 105 380

The positions of the horizon and of six distant lamps arranged in a vertical array were observed through a number of 24 hour periods. Two sensitive dip meters were used at stations whose elevations above mean low water were 14 feet and 117 feet The observations were made from the Chesapeake Bay Annex of the Naval Research Laboratory situated on the west shore of the bay near Chesapeake Beach, Maryland.
The results show the measured positions of horizon and lamps and the calculated (no refraction) positions. The temperatures of the water and of the air at the two observing stations are also shown.
Quantitatively, the results show a shift upward, or reduced dip angle, of the horizon and of the lamps when the air is warmer than the water and a shift downward, or increased dip angle, when the air is colder than the water. These shifts are more pronounced for lines of sight near the horizon and diminish as the line of sight is raised above the horizon.
On a day when the horizon was shifted by 4 minutes of arc the top light, whose horizon, was shifted less than 1 minute.
The most extreme shifts encountered were about +2 and -3 minutes of arc for the horizon and +2/3 and -1/3 minutes for the top lamp as viewed from 117 feet above the water. From the station 14 feet above the water the extreme shifts were +3-1/2 and -9 minutes of arc for the horizon and +1-1/2 and -0 minutes of arc for the top lamp.

A20 Atmospheric Refraction of Radio-Frequency Electromagnetic Waves
Nicholson, P. F.
NRL Rept. 5607
Apr 61 AD 256 768

Propagation of an electromagnetic wave through the earth's atmosphere is discussed. Even with the omission of effects due to the earth's magnetic field and deviations resulting from tropospheric and ionospheric inhomogeneities, ray tracing is quite difficult. The relatively simple method of dividing both the troposphere and ionosphere into a number of spherically stratified layers and summing progressively the refraction in each layer has allowed accommodation of a wide range of refractive index distributions. Several profiles have been selected to explore influences such as the diurnal, seasonal, and sunspot effects on the total atmospheric refraction. General changes in the tropospheric profile caused by fluctuations in relative humidity and other smaller effects such as perturbations of the upper profile are also discussed. From the given graphical presentations and suggestions for the programming of other relevant profiles, the tracking engineer or radio astronomer may easily determine the influential factors leading to a realistic assessment of a curve for refraction error suitable to his own particular situation.

A21 Atmospheric Refractive Index Fluctuations as Recorded by an Airborne Microwave Refractometer.
VonRosenberg, C.E.; Crain, C. M.; Straiton, A. W.
EERL Rept. 6-01 U. of Texas
Feb 53

This report presents a statistical analysis of atmospheric index of refraction fluctuations recorded by a direct-reading airborne microwave refractometer. Soundings were made at each of three locations from the surface level to about 10,000 or 12,000 ft. above mean sea level. The intensity and scale of these fluctuations were determined as a function of altitude. Probability distributions of intensity and scale are shown for each 1000 feet height interval, and for the interval from 2,000 to 12,000 feet.

A22 Atmospheric Refractive Index Measurements
Crain, C. M.
Ph.D. Dissertation U. of Texas
Jun 52

This report gives in chronological order the steps taken by C. M. Crain in modifying the Crain Refractometer so that it could be used to measure and record continuously the index of refraction of gases under varying circumstances. The refractometer was first constructed for laboratory use, then for near ground uses, and finally for use in Aircraft. The index of refraction of different gases at 9,340 megacycles are listed from laboratory, near ground, and airborne tests. Most parts of the report had been published in the scientific literature before publication of the thesis except the measurements of fluctuations and index profiles obtained using the refractometer onboard an aircraft, which are reported for the first time.

A23 Bibliography On Electromagnetic Wave Propagation
Matschlie, Arnold
Sylvania
Apr 59 AD 216 404

The purpose of this bibliography is to provide an up-to-date (1947-1958) reference to publications from laboratories foremost in their respective fields of upper atmospheric research, wave propagation, and wave scattering phenomena. The laboratories whose work in these fields has comprised the basis for this report are: Cavendish Laboratory, University of Cambridge; Electrical Engineering Department, Cornell University; Ionospheric Research Laboratory, Pennsylvania State University; Radio Propagation Laboratory, Stanford University; Stanford Research Institute.

A24 Calculator for Atmospheric Refractive Index
Anderson, L. J.
Rept. No. 279 U.S.N. Electronic Lab.
Mar 59

The calculator shown in this report provides a simple and accurate method of obtaining true and modified refractive index values from temperature, humidity, and altitude. Only re-setting is necessary per value of refractive index. Accurate pictures of the calculator are given.

A25 Calculations of Ground-Space Propagation Effects
Counter, V. A.; Riedel, E. P.
Rept. LMSD-2461
May 59 AD 162 000

This report is basically an extension of V.A. Counter's Propagation of Radio Waves through the Troposphere, LMSD-2066, 28 Dec. 1956. In this latest study the results of the computation of elevation angle and range deviations are presented along with the residual errors and corrections, Ionospheric altenuation, and the Faraday effect using the models and analyses developed in LMSD-2066. In addition, this analysis includes a more exact method of computation of the refraction through a tropospheric layer. Short discussions of the frequency dispersion, pulse degradation, and range resolution are also included. The results of machine calculations are presented in graphical form for seven operating frequencies, the lowest at 50 mc. An approximate but useful method using a "normalized despersion variable" is presented which enables many propagation problems to be solved quickly for any operating frequency above 100 mc.

A26 Catalogue of Microwave Refractive Index Recordings on File at the EERL

Unknown author
EERL Rept. 6-16 U. of Texas
Aug 56

This report summarizes and briefly describes the microwave refractive index and the occasionally associated temperature data, the original recordings of which are on file at EERL at the University of Texas. The data were taken with either ground based or airborne versions of the various models of the basic Crain microwave refractometer. The data is catalogued and arranged according to data running from January 1949 to May 1956.

A27 Catalogue of Ray Tracing Patterns through a Nonstandard Atmosphere

Hunt, Wade T.
Wright Air Development Division, USAF
Jan 61 AD 265 029

Sixty families of ray tracings are presented. Thirty of these families are traced using a thick layer (1000 ft. thick) and thirty are traced using a thin layer (200 ft. thick). These ray families give a picture of the radiation pattern with a transmitter at various altitudes relative to the layer in the atmosphere. A discussion of the propagation equation and how ray patterns are derived from this equation, starting with meteorological data, is shown. Radio holes, antiholes, and ducting are discussed. When layers occur in the atmosphere, the signal recieved from a transmitter will depend on the position of the transmitter and received relative to the position of the layer.

A28 Catalogue of Refractive Index Profiles Measured with Airborne Refractometers.

Unknown author
EERL Rept. No. 5-26 U. of Texas
Nov 57 AD 133 769

All known airborne microwave refractometer index of refraction profile data are presented in catalogue form. The number of profiles and dates of observation are listed for various geographical locations. Also, the agency (or agencies) responsible for the collection of the data, and information as to where the data might be found are given.

A29 Characteristics of Tropospheric Refractive Index Fluctuations Observed During a 1955 Measurement Program in the Colorado and Florida Areas

Crain, C. M.; Chapman, H.
EERL 6-12 U. of Texas
Oct 55 AD 79 979

An attempt is made to summarize certain of the larger scale features observed in a series of microwave refractometer observations taken from a B-25 aircraft flying in the Colorado and Florida areas from Feb. 20 to May 31, 1955. Consideration was given to such factors as the total RMS values of the variations of the maximum refractive index fluctuations, their power spectra, and the total variations over 900 ft. and 2700 ft. for each 3 minute recording period. On many of the flights, there were large variations within short distances of the refractive index variation-vs-altitude patterns. Those variations which have scales or distances ranging from a few hundred to a few thousand feet appeared to be associated with the increased moisture content of rising, thermally unstable, convective currents which are the energy and moisture sources for cumulus type clouds. No significant difference appeared between the pattern of these index variations for thermals or clouds. Another more unusual type of refractive index variation was noticed which had characteristic distances of about 10 times the magnitude of those associated with atmospheric convection.

A30 Charts of Corrections to Radar Observations for Refraction by Terrestrial Atmospheres
Taylor, P. B.; Engler, N. A.
Dayton U. Research Inst. Res. Rept. no. 427-71
Feb 60 AD 239 322

There are presented in chart form corrections for atmospheric refraction to observations of range and angular altitude of targets observed by electromagnetic radiation at either visual or radar wave lengths. These correlations have been computed for sixteen type atmospheres above a spherical earth. In these atmospheres the index of refraction attenuates exponentially with height. The type atmospheres covers a range of base indices and exponential attenuation rates.

A31 Climatic Charts and Data of Radio Refractive Index for United States and World
Bean, B. R.; Horn, J. D.; Ozanich, A. M., Jr.
NBS Monograph n22 p. 178
Nov 60

Included in this Monograph is a compliation of refractive index data. Data listings made up of observations from 45 U.S. surface weather stations for 2 hour intervals over an 8 year period are given. Mean values, maxima, minima, and standard deviations of the refractive index have been calculated and tabulated for these observations. Additionally, mean vertical profiles of the refractive index have been prepared for 43 U.S. upper air sounding stations from long-term means of pressure, temperature, and humidity.
Earlier studies of refractive index climate are assimilated and put into prespective. One such study is an extensive analysis and mapping of the refractive index climatology is developed based upon monthly mean observations of pressure, temperature, and humidity.

An important finding of these climatological investigations is the strong correlation of N with height. A reduced-to-sea-level value of the index, termed N_o, is used to eliminate this systematic height dependence. The surface value of N, N_s, may be estimated four to five times more accurately from charts of N_o than from similar sized charts of N_s itself. From climatic charts of N_o, N_s may be estimated at any given location in the United States throughout the day during every season. In addition detailed annual and dirunal cycles, as well as 8 year cumulative probability distributions, are given for 12 representative U. S. stations.
On a worldwide basis, charts of mean N_o are presented for both summer and winter season.

A32 Climatology of Atmospheric Refractive Index at Radio Frequencies
Mitchell, Myles M.
WADC Tech. Rept. 57-610
Oct 57 AD 142 019

The study of the climatology frequencies in the troposphere is based on radiosonde data for the year 1955 and 1956 taken at Wright Patterson Air Force Base, Florida. The complete data, some 4200 soundings, have been analyzed. The refractive index profiles, for a full year at Patrick AFB, are included in the text. The observed trends in the occurance of super-standard layers are presented graphically and related to other meteorological phenomena. The study has been prepared for use as an aid in forecasting atmospheric conditions which affect radio propagation.

A33 Climatology of the Radio Refractive Index Near the Ground for the United States
Bean, B. R.; Ozanich, A. M., Jr.
NBS Rept. 6030
Dec 58

The radio refractive index of air is a function of atmospheric pressure, temperature, and humidity and is found to vary in a systematic fashion with climate. It was found that the surface value of the refractive index may be estimated four to five times more accurately from charts of reduced-to-sea-level values than from similar-sized charts of surface index. Climatic charts are presented so that the surface refractive index may be estimated at any location in the United States throughout the day during each season of the year. Detailed annual and diurnal cycles, as well as eight year cumulative distributions are also given for twelve stations located throughout the United States.

A34 On the Climatology of the Surface Values of Radio Refractivity of the Earth's Atmosphere
Bean, B. R.; Horn, J. D.
NBS Rept. no. 5559
Mar 58

World wide maps of the monthly mean value, N_s, of the radio refractivity of the atmosphere near the earth's surface are given in terms of the refractivity reduced to sea level: $N_o = N_s \exp.(+0.03222h)$, where h is in thousands of feet. The use of N_o: (a) allows refractivity contours to be derived even in areas where the terrain changes rapidly and; (b) reduces the range of refractivity isopleths by about one third. A map is also given on the maximum range of monthly mean values of N_s. Examples are given of the application of these data to the prediction of: (a) the total bending of radio rays and ; (b) the geographic seasonal and year to year variation of VHF-UHF radio transmission loss.

A35 Cloud Refractive Index Studies
Campen, C. F., Jr.; Cunningham, R. M.; Plank, V. G.
Cambridge Res. Center Geophysics Res. Paper No. 51
Oct 56 AD 110 259

Special problems inherent in the measurement of refractive index in cloudy regions are considered and reasons for refractive index change in and near clouds are discussed. Various theories of cumulus convection are reviewed for later reference.
Measurement methods, data gathering procedures, and analysis aims and techniques are described. Data analyzed to date are presented and the tentative conclusion is drawn that with judicious use of radiosonde data a good estimate can be made of the refractive index changes in and around clouds. The complex character of these refractive index changes is tentatively explained.

A36 Cloud Refractive Index Studies Part I Gradient Distributions
Braham, R. R.; Harrington, E.
Tech. Note No. 11 Cloud Physics Lab. U. of Chicago
Mar 58

A study has been made of the small-scale gradients of refractive index found within and around a group of 71 cumulus clouds studied 15 and 19 June 1956 in the vicinity of the Bahama Islands. Data were obtained with a University of Texas microwave refractometer mounted in an Air Force B-29. These flights were a part of the Air Force Geophysics Research Directorate program of refractive index studies.
The magnitude of the refractive index gradients and the space distances over which they extended were evaluated for approximately 80,000 gradients. These are analyzed in terms of the altitudes of measurement and locations with respect to cumulus clouds. An attempt has been made to study moisture conditions at cloud boundaries through an interpretation of the refractive index data obtained.
It is shown that the small-scale gradients of refractive index around cumulus clouds is a function of height and position within or about the clouds. In general the gradients reach their maximum intensity near the cloud base and in the turbulent zone near the cloud edges.

A37 Cloud Refractive Index Studies Part II Use of Distribution of ΔN vs. ΔS for Estimating Mechanical Turbulence.
Braham, R. R., Jr.; Harrington, E. L., Hoffer, T. E.
Tech. Note no. 77 Cloud Physics Lab. U. of Chicago
Aug 58

An analysis has been made of fine structure variations of refractive index in and around a group of about 70 cumulus clouds with a view toward relating these variations to mechanical turbulence parameters.
Frequency distributions of refractive index gradients were prepared for each level of flight for clear air, cloud core and regions of transition at the cloud boundaries. Similar distributions were prepared for refractive index increments. The latter distributions, in the form of tables of N change vs. gradient size (ΔS), are presented as an appendix. From these distributions a parameter analogous to the "mixing length" of early turbulence theory was computed.
This study shows that eddies of the transition regions of cumulus clouds have dimensions of a few tens of meters and are carried for distances of the order of 30-50 meters before losing their identity. Mixing lengths of clear air eddies are much larger than those of cloud eddies, except, possibly, for those eddies in the uppermost parts of the clouds.

A38 Cloud Refractive Index Studies Part III
Harrington, E. L.
Cloud Physics Lab. U. of Chicago Tech. Note no. 21
May 60 AD 239 789

Statistical analysis of refractive index gradients was applied to some measurements made in the sub-cloud layers at altitudes from 1,000 to 3,000 ft. over the Caribbean Sea. The data were arranged in bivariate frequency tables of ΔN vs ΔS. Tests were made to determine if these distributions changed with respect to altitude and horizontal location, and to see if the distributions representing cloud air were different from the clear-air distributions. These tests revealed a high degree of sampling variability which masked any other variability which might be present. The distributions of ΔN show that over 90% of the values are less than one N unit, reflecting the high humidity encountered at these altitudes.
A correlogram for a record of data gathered entirely in clear air showed high positive correlation over a distance of about 28KM. The integrated refractive index change along the aircraft flight path in cloud was computed for a number of clouds from both the subtropical oceans and the continental U.S.
A difference in the size distribution of the integral function between the ocean and continental clouds is attributed to a biased sampling of the ocean clouds with respect to cloud environment refractive index difference.

A39 Comparison of Computed With Observed Atmospheric Refraction
Anderson, W. L.; Fannin, B. M.
UNM Tech. Rept. EE14
Aug 58 AD 203 893

Radar observations (X -band), with a quoted accuracy of 0.25 mils or better have been collected for 69 cases, involving 40 days, during the period November 1, 1957 through March 25, 1958. The radar was located at the White Sands Proving Ground New Mexico, and the target in each case was a beacon located on Alamo Peak, giving a range of about 48 miles and an elevation angle of 14.766 mils.
For the days for which radar data are available, theoretical values for the refraction-induced error have been computed using ray theory methods and measured meteorological data. Total observed elevation-angle error ranged between 0.57 and 2.27 mils, with the standard deviation being 0.39 mils. Under the conditions of this experiment, the use of ray theory methods and the assumption of horizontal stratification in the atmosphere seemed to be justified.

A40 Comparison of Experimental with Computed Tropospheric Bending
Anderson, W. L.; Beyers, N. J.; Rainey, R. J.
UNM Exp. Sta. Rept. EE28 AD 287 498

Limits of applicability of ray tracing in computing tropospheric refraction at White Sands Missile Range have been further explored. 286 comparisons were made, all for a path from radar to fixed beacon of about 45 miles and an elevation angle of 18.32 mils (mils=$3.2/\pi$ x milliradians). A horizontally stratified atmosphere was assumed. Refractive index profiles were prepared from a variety of weather data and classified "A", "B", or "C" in decending order of reliability prior to ray tracing calculations for each of the radar readings (165 cases); in 143 cases profiles based only on radiosonde data were also included for comparison with the "A","B", or "C" results.
Angle observations were made with an FPS-16 C-Band radar having a quoted instrumental accuracy of 0.14 mks RMS, angle readings varied from 18.70 to 20.92 mils with a mean of 19.37 mils and a standard deviation of 0.42 mils
The RMS deviation of computed from experimental angle ranges from 0.29 to 0.42 mils for different classes of data. The ratio of this deviation to the deviation from overall mean varies from 0.69 for Class A to 1.04 for Class B. Thus the improvement over a "standard atmosphere" varies from 31.7 to -4% and correlates directly with quality of weather information. For this experiment it is concluded that most of the RMS elevation angle error is contributed by atmospheric uncertainties. Although ray tracing methods provide a significant correction when sufficiently good weather information is available, there still remains a large uncertainty not accounted for by equipment.

A41 Comparison of Measured and Computed Refractive Bending in the Troposphere.
Anderson, L. J.; Trolese, L. G.; Smyth, J. B.
Presented to URSI 12th General Assembly
1957

Tropospheric bending measurements were made at 418 mc and 1809 mc under a variety of refractive conditions. Measurements were made by a sea-interferometer technique, whereby an airplane carrying the two transmitters flew over the sea at constant altitude toward the receiver site, which was located overlooking the sea. The maximum and minima caused by interference were used to locate points on the path. The measured bending was compared with values computed from radiosonde data. Experimental accuracy was estimated at ± 0.1 milliradian. Differences between observed and computed bending averaged ± 1.0 milliradians with extremes of ± 0.2 milliradians. Differences were greatest under strong ducting conditions and smallest under near-standard conditions. The authors conclude that the differences represent the limit of accuracy which is imposed upon bending calculations as a result of the non-uniformity of the atmosphere.

A42 A Comparison of Observed Amplitudes of Tropospheric Index of Refraction Fluctuations with those from Observed Median Transmission Losses.
Edmonds, F. N.
EERL 6-27 U. of Texas
Aug 58 AD 160 831

A relationship derived from scatter propagation theory and based on the measured fluctuation spectra is given between the radio transmission loss and the square of the amplitude of the refractive index fluctuations. A value was calculated of the square of the index fluctuations, accounting for the Mean radio signal level on each of 14 NBS radio paths originating in the Camp Carson area. The path lengths varied from 97 to 226 mi. The measured index of refraction parameter is approximately the same as that required to explain the radio signal strengths on the shorter paths by the scattering theory. The conclusion is not felt to be conclusive because the shorter paths could conceivably be in the diffraction field. The measured index fluctuations are greater than those required to explain the radio signal levels at greater distances. A possible explanation is that the meteorological conditions adjacent to the mountains may not be representative of those on the plains further east. The data needed to confirm this possibility are not available. A need for a more comprehensive test is indicated.

A43 Comparison of Observed Tropospheric Refraction with Values Computed from the Surface Refractivity.
Bean, B. R.
NBS Rept. 6753
Mar 61 See Periodical P33

Radar elevation angle errors observed in the Tularosa Basin of New Mexico are compared with values predicted from the surface value of the radio refractive index. Although this method of prediction is not particularly efficacious under the conditions of this experiment encouraging agreement was nevertheless obtained between predicted and observed (a) mean value of elevation angle error; (b) variation of elevation angle error with N_s; and (c) the degree of reduction in the uncertainty of prediction gained over the use of a single standard atmosphere.

A44 Convection and Refractive Index Inhomogeneities
Plank, V. G.
Pergamon Press Ltd. Ireland
1959 See Periodical P39

This paper reviews certain observations and theories in the field of cumulus convection and attempts to integrate them into a more or less comprehensive picture. The picture will then be interpreted in terms of refractive index structure.

A45 Correlation Between Measured Path Function and Relative Humidity
Boileau, A. R.
Visibility Lab. SIO Ret. No. 59-5 U. of California
Feb 59

The Visibility Laboratory of the University of California, La Jolla campus, is engaged in an on-going research program studying image transmission through the atmosphere. The paper "Image Transmission by the Troposphere I," 4 published in the Journal of the Optical Society of America, discusses this program. In that paper correlation between certain optical and meteorological parameters is indicated. The study of this correlation has continued and this report describes the results of data gathered from a second formation flight of two airplanes the instrumented B-29 and a microwave refractometer-equipped C-131 from Patrick AFB squadron.
It was found that when the relative humidity is high, approximately 85% and higher, small changes in relative humidity are accompanied by large changes of path function, i.e., the scattering of radiant flux from particles in the air; when the relative humidity is approximately 60% or lower, large changes in relative humidity are accompanied by small changes of path function; and in the range of relative humidities from 65% to 85% a more complicated relationship between relative humidity and path function exists.

A46 Correlation of Tropospheric Refractive Index Fluctuations with Synoptic Meteorological Data.
Moyer, V. E.
EERL Rept No. 6-14 U. of Texas
May 56

This investigation has undertaken the explanation of several unusual horizontal fluctuations of atmospheric refractive index in terms of variations of meteorological parameters. It is seen that large-scale fluctuations of refractive index, as determined by an airborne refractometer being flown laterally over land, can be attributed to (1) air volumes released through convection, (2) air volumes released by frontal activity, and (3) air volumes released by mechanical trubulence. Once again the concept of homogeneous air masses is found to be an unrealistic idealization. Moreover, the occurrence of smoothly delineated frontal zones separating such air masses appears to be a fictitious expedient: the ordinary front is seen to be a highly irregular mixing zone wherein is contained a conglomeration of air volumes of both air masses. These air volumes, of all dimensions, appear to retain their air-mass identity for finite, through unspecified, period of time. This, the concept of the frontal zone as consisting of air that represents a transition between the air masses is thought to be unrealistic.

A47 Cumulus Climatology and Refractive Index Cloud Refractive Index Studies, II
Cunningham, R. M.
AF Cambridge Res. Labs. Geophysics Res. Dir.
Jan 62 AD 275 124

Earlier investigation shows that the most abrupt changes in refractive index to be encountered in the atmosphere are found in and about cumuliform clouds. Values of the difference in refractive index between that in a cloud and in the environment measured by a refractometer compare favorably, on the average, with those obtained from radiosonde data and an estimated cloud sounding.
As a result of the study given in the first report (published in 1956), climatological data on atmospheric soundings, cloud-base-heights, and percentage frequency of occurrence of cumuliform clouds can be utilized here in the estimation of the chances of occurrence of various values of this refractive index difference over the United States for the four seasons.

A48 Data for Predicting Dependable Air-to-Air Radar Range
Hinds, Chester, A.
WADC Tech. Rept. no. 56-232
Arp 56 AD 101 277

A need exists throughout the Air Force and other agencies of the Dept. of Defense for a compilation of information which can be used to predict the maximum dependable radar range when both the radar and targets are above a super-standard layer in the atmosphere. This report contains tabulated and graphically presented data which, if used properly, can quickly provide vital information on the dependable maximum radar range under conditions stated above.
Data were determined through the application of the radio line-of-sight equation. This application of the equation and the accompanying tables are believed to be new.
Since the primary purpose of this report is to provide prediction data which can be used easily by crew members, many of whom will not have had scientific, technical, or even specialized training

in radio wave propagation, theory has been held to a minimum. Only a brief discussion of the refractive properties of the atmsophere has been given. An elementary treatment of tropospheric radio wave propagation has been included in order to give the uninitiated sufficient background for applying the microwave refractometer, the tables, and the distance chart to the problem of determining the extreme of dependable radar coverage in an operational situation where both targets and radar are above a layer. Such factors as transmitter power, two-path transmission, etc., which might be treated as unique to a given equipment or application, are not considered in this report.

A49 Determination of Modified Index of Refraction Profiles and Wave Attenuation from Radio Data.
Straiton, A. W.; LaGrone, A. H.
EERL no. 25 U. of Texas
Apr 49

In this report, the attenuation factor and modified index of refraction height curves are determined from radio data and compared with the meteorologically measured modified index of refraction curves and the related attenuation factor. The wave length used was 3.2 cm. Four individual sets of radio data with overwater path lengths of 12.3 , 31.6, 40 and 47.4 miles are considered and related to the average meteorological conditions.

A50 Diffraction, Refraction and Reflection of Radio Waves
Fock, V. A.
AF Cambridge Res. Center Antenna Laboratory
Jun 57 AD 117 276

The Soviet physicist V. A. Fock is well known by physicists for his work in Quantum mechanics, particularly in connection with the Hartree-Fock theory of self-consistency fields. The purpose of this collection is to aquaint the reader with Fock's more recent work on the propagation, refraction, and diffraction of radiowaves. Fock's early papers' on this subject (the first five papers in this collection) appeared in English almost a decade ago. However, all of his more recent work has been published in Russian and is relatively unknown outside the Soviet Union.
The translations in this collection have been based upon translations obtained from several sources.

A51 Discussion of Radar Errors Due to Propagation Effects.
Anderson, W.; Fannin, B. H.
Tech. Rept. EE16 U. of New Mexico
Aug 58 AD 203 894

This report contains brief writings on a number of subjects associated with propagation-induced radar errors. The purpose of this report is to give, under one cover, brief discussions of some of the fundamental topics in this field to serve as a convenient reference for persons without an extensive background in propagation in propagation problems. The intent is not to present new, advanced, or highly technical information but rather to present the fundamentals in a clear and simple, though brief, fashion.

A52 Distribution of Refractive Layer Over the North Pacific and Arctic
Gossard, E.; Michaelis, J.
Rept. No. 841 USN Electronics Lab.
Apr 58 AD 205 224

A study was made to determine the distribution and intensity of refractive layers over the North Pacific and Arctic-areas. Refractive index distributions are plotted, by seasons, for both areas. Charts of percentages of all, refractive layers between the surface and 700 millibars for twenty stations are included. There is a further breakdown of very super-' refractive layers into cumulative frequency distributions of layer thickness and intensity vs. height of their bases.

A53 Diurnal and Interdiurnal Variations of Radar Elevation Errors for Selected U. S. Locations
Fannin, B. M.; Jehn, K. H.
EERL Rept. 7-02 U. of Texas
Oct

The refractive-index variations in the atmosphere cause errors in radar measurements of elevation angle. This report presents the results of a study of hour-to-hour and day-to-day variations of this error.

In order to get information concerning the spread in propagation errors to be expected during a particular season for fixed locations, theoretical elevation angle errors have been computed on the basis of standard Weather Bureau meteorological data for station representative of the West Coast, East Coast Gulf Coast and Central Interior of the U.S. For each station the 0300Z soundings for the odd days of the month were employed for January for the years 1950-1954 and July for 1950-1953. From the computed values, error distribution curves are presented for each station and season for two target heights for each of two elevation angles.

In order to get an indication of the amount of diurnal variation to be expected in propagation errors, an analysis has been carried out on the surface refractive-index values for four locations selected to correspond closely with those used in the day-to-day variation study. The following surface refractive-index data have been included in the investigation: values at three-hour interval for all stations for both January and July for 1953, at six-hour intervals for all stations for July in 1951 and 1952, and at six-hour intervals for all stations for January 1952 and 1954 (except the Lake Charles January values are for 1951 & 1952). The results of this surface refractive-index study can be interpreted in terms of elevation-angle errors due to the good correlation between surface refractive index and elevation angle error for high targets. In order to aid in this interpretation and in determining to what extent such a procedure is meaningful, the elevation angle errors computed in the day-to-day variation study have been plotted versus the surface refractive index for each combination of station, season, elevation angle, and target height.

A54 Doppler Errors Caused by Variations in the Electromagnetic Properties of the Atmosphere.
LaGrone, A. H.
EERL Rept. no. 7-12 U. of Texas
Sep 57 AD 148 443

Variations of the index of refraction along the wave path produced errors in the Doppler radio systems measuring target velocity. The nature of the Doppler error is described for errors caused by a constantly changing refractive index distribution over a path and by the curvature of the ray. Variations of the index of refraction with time over a fixed radio path generated a Doppler noise in the signal at the receiver. Variations with height caused by a curved path for other than normal incidence and resulted in an error in the determination of radial velocity by Doppler measurements. The Doppler noise generated by atmospheric refractive index variations between 2 fixed points was determined for a 7 mi. path. The noise appeared negligible. The error caused by the curvature of the radio path was computed for day and nighttime models of the atmosphere for a frequency of 30 mc and an elevation angle of 20°. The error caused by the curvature is negligible for evaluation angles greater than 70°. The error was more significant where the angle was small and the target was in or beyond the ionosphere.

A55 The Effect of Atmospheric Horizontal Inhomogeneity Upon Ray Tracing.
Bean, B. R.; Cahoon, B. A.
NBS Rept. 6054
Nov 59 See Periodical P45

The tracing of radio rays is normally carried out under the assumption that the refractive index varies only in the vertical direction. Although this assumption appears to be quite reasonable in the average or climatic sense, it is seldom satisfied under actual conditions and is strongly violated by horizontal airmass changes occurrency near frontal and land sea interfaces. This latter case is investigated by tracing rays trough two instances of observed marked horizontal variation of the refractive index. The bending for these ray paths was then compared with values obtained under the normal assumption of horizontal homogeneity.
Although at 1 kilometer and above these horizontal changes appear to have little effect, rays emitted at low elevation angles are sensitive to extreme horizontal variations of the atmosphere near the surface, such as those associated with

ducting conditions. However, since it appears that such conditions appear less than 15% of the time in most locations, the majority of ray path calculations may be carried out under the normal assumption of horizontal stratification of the refractive index.

A56 The Effect of the Atmosphere Refractive Indexes on the Accuracy of Dovap
Otterman, J.
Aug 58 AD 203 897

This report discusses to what extent the refractive indexes in the atmosphere affect the DOVAP accuracy. The basic DOVAP equation is derived and applied to propagation under the conditions of varying refractive indexes due to air density and ionization. It is suggested that a small improvement in position determination can result if a variable average velocity of radio waves, as a function of altitude, is used. Calculations indicate that the ionosphere propagation will have only a very small effect on the accuracy at altitudes under 90 km. The effect of the curved propagation path, i.e., the difference between the actual propagation path and the straight-line distance, has been shown to be negligible, contrary to previous estimates of the effect.

A57 The Effect of Radiosonde Time Lag on Index of Refraction Layer Height, Thickness, and Gradient
Wagner, N. K.
EERL 6-33
Apr 60

The height and thickness of anomalous layers in the atmosphere reported by the radiosonde differ from time height and thickness as a result of sensing element time lag. Correction factors are derived for various combinations of time lag and layer thickness by employing a standard form of the time lag equation and minimax curve fitting techniques. Emphasis is placed on radiosonde distortion of index of refraction layers; however, the technique employed is not restricted to this application.

A58 Elevated Duct Between San Diego and Hawaii
Rept. of NRL Progress pp. 1-13
Unknown author
Apr. 61

Elevated duct measurements, both radio and meteorological, have been made in the Bahamas between Recife, Brazil and Ascension Island, and between San Diego and Hawaii, Analysis of measurements made at 220 Mc, 445 Mc, 1250 Mc, and 9375 Mc show that the radio signals peak at the tradewind inversion altitude and that attenuation rates in the elevated duct are always less than 10 db per 100 nautical miles. The average signal strength below the inversion altitude is weaker than it is at the inversion level; it appears to be less dependent upon altitude above the inversion level. Other measurements made in the same areas indicate gross correlations of attenuation rate with refractive index and cloud cover data.

A59 Elevated Duct Propagation in the Tradewinds
Ringwalt; MacDonald
NRL Rept. 5602
Jun 61 See Periodical P53 AD 262 042

All of the maximum propagation ranges (at 220 mc) observed in an elevated duct region varied from 500 to 1200 miles, compared to less than 400 miles observed with the same equipment outside the duct. The measurements were made at the optimum season (November) in a trade-wind region between Brazil and Ascension Island (8° S latitude). The field strengths above 400 ft. are as much as 40 db larger than those at lower altitudes. From the level at average duct height (6,000 ft.) the field decreases slowly to 10,000 ft. the maximum altitude investigated. The slow fading rate usually associated with duct propagation is not always observed, even on the very long range runs. An extrapolation to propagation conditions in the month of March via refractive index measurements indicates minimal ducting conditions 10 to 20% of the time.

A60 An Elevation of Radar Corrective Systems
Beyers, N.; Hinds, B.; Hoidale, G.
WSMR MGD Progress Rept. no. 7
Jun 59

Several radar refraction corrective systems are described and evaluated. The technique is based on a fixed radar beacon and permits an accurate check on corrective system results at a low elevation angle (18.32 mils) and moderate range (45 miles) A specialized system is introduced which differs from others in that it utilizes a fixed radar beacon to measure the refractivity along the propagation path.

A61 Errors in Altitude Triangulation Caused by Variation in Index of Refraction
Page, R. M.; George, S. F.
NRL Rept. 3844
Jun 51

A theoretical analysis is presented of the effect of a variation in the atmospheric index of refraction on the elevation angle and range as measured by a radar system. Formulas are developed which express the errors in angle and range as functions of the actual target altitude and range, and the index of refraction. On a percentage basis, the elevation angle errors far exceed the range errors. Altitude error curves for both angle and range triangulation are presented by the use of two assumed functions to fit emperical index of refraction data. These curves show that for long range low-flying targets range triangulation can at times produce greater errors in altitude than angle triangulation. The relatively large errors revealed by this study point to the need for a good method of measuring accurately the refractive index gradient.

A62 Errors in the Measurement of Angle-of-Arrival Resulting from Overwater Refraction
Gerhardt, J. R.
EERL Rept. 3-01 U. of Texas
Jul 51

Using ray tracing procedures, errors in the measurement of angle-of-arrival of incoming radiation resulting from atmospheric refraction are determined for a number of meteorological conditions existing overwater.

A63 The Estimation of Atmospheric Refraction From Aximuth and Elevation Data
Richardson, D. J.
Royal Aircraft Establishment (Gt. Brit.)
Feb 53 AD 7829

A method is given which corrects the position fixes obtained from azimuth and elevation readings for atmospheric refraction. The effect of refraction is included as an additional unknown term in the equations of condition. The refraction is determined simultaneously with the position coordinates in the least-square solution of the equations.

A64 An Evaluation of Radar Corrective Systems
Beyers, N. J.; Hinds, B.; Hoidale, G.
Progress Rept. no. 7 WSMR
Jun 55

White Sands site to SAC Peak path geometry is discussed. Equation for refractivity in terms of pressure temperature, water vapor is given. Three classes of meteorological data are defined. Results of 64 cases from 3 July '58 to 17 Dec.'58 as analyzed by Fannin-Jehn are presented on scatter diagram of computed vs. observed mils. 52% of corrections within .2 mils and 80% within .4 mils for all classes met data together. The "RA" system was described which corrects according to an exponential estimate of the refraction profile whose constants are dependent upon the surface index. The results using this correction are presented in a scatter diagram and the Fannin-Jehn and RA methods are compared in a cumulative frequency distribution of error versus percent of cases. 0.2 mils is considered a satisfactory correction in this report. Another method is discussed wherein the exponential estimated profile is further corrected using a beacon shot.

A65 An Experiment Study of Substandard Propagation over an Optical Sea Path at 3 CM Wavelength.
Kiely, D. G.; Carter, W. R.
ASRE Tech. Rept. no. TX-51-1
Jan 51 AD 42 366

This paper describes an experimental study of Sub-Standard propagation over an optical sea path at a wavelength of 3 cm for the period July 1950 to January 1951. The object of the investigation was to record the general fading characteristics (i.e. depth, duration and frequency of occurrence) for summer, autumn and winter seasons and to present the results in such a form that the effects os sub-standard propagation on the operational ranges of radars and radar beacons could be readily appreciated. An initial assessment of the transmitter power required for reliable operation of a beacon under given conditions has also been made.

A66 Experimental Determination of Tropospheric Bending Part I & II
Anderson, L. J.; Trolese, L. G.; Smyth, J. B.
SRA-6 SRA-7
Apr 56

A convenient method for computing elevation angle errors caused by tropospheric bending is presented. The feasibility of making experimental observations of tropospheric bending using the interferometer technique is studied in detail. Results are presented for our experimental program conducted along the coast line.

A67 Field Strength Determination by Ray Tracing Techniques for Horizontally Stratified Layers
Fannin, B. M.
EERL Rept. 6-04 U. of Texas
Aug 53

Radio field strength contours, based upon ray theory computations, are presented for sixty trilinear profiles of refractive index. The atmosphere is assumed horizontally stratified and the effects of the earth and antenna patterns are neglected. The contour configurations fall into groups possessing distinguishing characteristics that are summarized and discussed. A development of the principal concepts and techniques involved in ray theory is given in the appendixes. More advanced approximations are also given for two sets of conditions.

A68 Final Report
Unknown author
EERL Rept. no. 6-19 U. of Texas
Mar 57 AD 117 023

This is a review of the work conducted under contract AF 19(604)-494 concerning the measurement of index of refraction in the troposphere with an airborne refractometer and analysis of the obtained data. The scope of the work referenced in this final report is quite broad. A bibliography of all reports published under the contract is included.

A69 Final Report of Radio Results for 1955 Gulf of Mexico Propagation Tests.
Brooks, F. E.
EERL Rept. 3-21 U. of Texas
Mar 57

During late spring of 1955, the EERL of the University of Texas conducted field measurements of the overwater propagation of microwaves at low elevation angles. These tests were designed to substantiate a phenomenological model for low angle propagation and to determine experimentally the parameters of the model.
Measurements were made at 5.3 cm, 3.2 cm, and 8.6 mm wavelengths with various antenna systems to produce various degrees of illumination on the water surface. Meteorological and oceanographic data were also obtained for correlation with the radio data. This report is the final report covering the radio propagation phase of the measurement program.

A70 Final Report of Meteorological and Oceanographic Results for 1955 Gulf of Mexico Propagation Tests
Wagner, N. K.; Gerhardt, J. R.
EERL Rept. 3-22 U. of Texas
Mar 57

In the spring of 1955 an overwater measurement program was conducted about thirty miles off the coast of Louisiana on two oil drilling platforms in the Gulf of Mexico. A series of micrometeorological and oceanographic measurements was taken in conjunction with radio propagation tests. The program was designed so that the resulting meteorological data would: (1) help the radio engineer to determine which atmosphere and sea surface variables affect the reflection of radio signals, and (2) be of interest from a strictly micrometeorological standpoint. Meteorological data were obtained with a number of instruments ranging from standard three-cup anemometers to the Crain microwave refractometer. Gulf wave heights were measured with a step gage, while the longer period variations were obtained by means of a surf beat gage designed and built at the Applied Physics Lab. of John Hopkins University. This report presents the analysis of the meteorological and oceanographic data along with a description of the instrumentation. A companion final report for the radio results has been prepared as EERL Rept. 3-21 (CM-394) and two reports have been issued devoted exclusively to the presentation of data.

A71 Final Report on Phase Stability Studies of Ground-to-Ground Microwave Links
Thompson, M. C.; et. al.
NBS Rept. 6702
Jun 60

A series of eight field experiments were conducted in 1958 and 1959 to study the variation in the phase of signals propagated over ground-to-ground microwave links (i.e. the variation in apparent path length) and the corresponding variations in radio refractive index and other atmospheric parameters measured at the path terminals.

This report includes a detailed description of the various propagation paths used, both in Colorado and Florida, and the equipment and techniques employed. Numerous pictures are shown. It also includes an analysis of longterm variations in the apparent path length and associated variables recorded during each experiment, and a power spectrum analysis of short-term variations in apparent path length and refractivity observed in three representative experiments.

A72 A First Order Approximation Correction of Radar Elevation Angles for Tropospheric Refraction
Dixon, H. M.
WSPG Tech. Rept. 18E
Jan 57

From an analysis based upon Fermot's principle of least time of path of the ray of electromagnetic radiation in the earth's atmosphere, a first order approximation has been derived to correct measured radar elevation angles for atmosphere refraction. By means of an experimentally evaluated function, it appears that any given atmospheric conditions can be approximated.

A73 First Quarterly Report for Electromagnetic Propagation Study
Solem, R. J.; Marion, T. M.
WMEC Motorola Inc. Reference Systems Lab.
Dec 57 AD 157 751

This is an introduction to studies of propagation modes and effect on accuracy of distance measurements by means of AN/PPN-13 equipment. Error corrections due to terrain scattering, obstacle diffraction, and refractive index variations are discussed.

A74 Forecasting Refractive Index Profiles in the Atmosphere.
Cowan, L. W.
Tech. Paper No. 2 ADC Forecast Ctr.
Sep 53 AD 36 347

The general meteorological aspects of the radio meteorology problem are summarized. Consideration is given to air masses, physical processes influencing refraction, and local refractive effects resulting from meteorological phenomena. Typical winter and summer modified refractive-index profiles are given for air masses in their source regions, and meteorological properties for the source regions are listed. Several experimental forecasting methods are discussed, including specific methods which apply to forecasting advective and nocturnal ducts. A radio climatology section presents data on the occurrence of ducts to aid in forecasting as a substitute for actual experience, and to provide a basis for meteorological consultant services. Histograms show the characterisitcs of elevated layers at 15 selected stations. A summary of shipboard measurements off the California Coast is also included.

A75 Further Airborne Measurements of Atmospheric Refractive Index Microvariations
Crain, C. M.
EERL Rept. no. 5-18
Sep 56

This report presents an analysis of atmospheric refractive index data taken by the Propagation Section of the Wright Air Development Center in the vicinity of Colorado Springs, Colorado, in March 1955 and in the area between the Florida Coast and the Bahama Islands in October 1955. Power spectra for variations having a spatial distribution in the range of about 3000 to 70 ft. were obtained for the Colorado data and the range of about 1250 to 25 ft. for the Florida Coast data. The RMS value of the variations in these portions of the spectrum lay in the range of a few hundredths to a few tenths of an N-unit for both sets of data. In appropriate evaluation of the Booker-Gordon scattering parameter $\Delta N^2/L$ was made for the Colorado data for comparison with the data obtained in August 1954.

A76 Further Studies of the Variations of Radar Elevation Angle Errors for Selected U. S. Locations.
Jehn, K. H.; Koscielski, A.; Fannin, B. M.
EERL Rept. no. 7-07 U. of Texas
Oct 55

Refractive index variations in the atmosphere cause errors in radar measurements of elevation angle. This report presents the results of a study of hour-to-hour and day-to-day variations of this error for five U. S. Locations (in addition to those already presented in EERL Report 7-02.
In order to get information concerning the spread in propagation errors to be expected during a particular season for fixed locations, theoretical elevation-angle errors have been computed on the basis of standard Weather Bureau meteorological data for U. S. stations representative of the northern continental interior, the Great Lakes region, the Southern California coast, the arid Southwest, and the Southeast U. S. Coast. These regions supplement those previously reported. For each station, the 0300Z soundings for the odd days of the month were used for January and July, 1950 through 1954. From the computed values, error distribution curves are presented for each station and season, for two target heights for each of two elevation angles.
In order to get an indication of the amount of diurnal variation to be expected in propagation errors, an analysis was carried out on the surface refractive index values for five locations selected where possible to correspond with those used in the day-to-day variation study. The results of this surface refractive index and elevation-angle for high targets. In order to aid in this interpretation and in determining to what extent such a procedure is meaningful, the elevation-angle errors computed in the day-to-day variation study have been plotted vs the surface refractive index (scatter diagrams) for each combination of station, season, elevation angle, and target height.

A77 Further Synoptic Analyses of the Atmospheric Refractive Index Climatology of Alaska.
Moyer, V. E.
EERL Rept No. 5-16 U. of Texas
Sep 56

This report is the second article published by EERL on an investigation of one concept of the radio climatology of Alaska and its contiuous waters and land masses. The synoptic climatology of the atmospheric refractive index for the month of February 1954 was obtained by comparisons of radiosonde-evaluated refractive moduli, N, also called the refractivity with refractometer-measured refractivity. It was found that this technique of charting the quasi-horizontal distribution of refractive modulus, N, at the 850-mb level, appeared equally promising as a synoptic climatological tool as it had in a previous month. Hence, it is concluded that it is equally reliable throughout the year. This study was motivated by urgent need on the part of defense radar systems.

A78 Generalized Earth's Curvature Correction
Glass, B. V.
AD 122 260

The general "earth's curvature correction" is given for correcting readings obtained from angle measuring instruments located on the earth's surface.

A79 Horizontal Angular Error Statistics Preliminary Report
Thorn, D. C.; Rainey, R. J.; Cramond, W. R.
UNM EE-41
Feb 61 AD 287 229

This reports contains a brief discussion of the azimuthal bending observed in 378 cases at White Sands Missile Range with a FPS-16 Radar. The distribution of azimuth Angles is shown along with the maximum & minimum values, mean, and standard deviation.

A80 Horizontal Microwave Angle-of-Arrival Measurements along the Coast Line near Corpus Christi, Texas
Straiton, A. W.; Gerhardt, J. R.; Gordon, W. E.; Williams, C.E.
EERL Rept No. 7 U. of Texas
Dec 46

This report covers horizontal microwave angle-of-arrival measurements taken along a coastal path of length of 6.89 miles. Horizonal angle and corresponding field strength values were obtained as a function of time and transmitter height. It is illustrated that the measured angular errors show a general correlation with measured horizontal gradient of index of refraction. It was also found that small deviations of the angle-of-arrival in a landward direction from the geometric path existed nearly all the time. Meteorological sounding showed overwater ducts were also present nearly all the time. The shape of angle-of-arrival transmitter height curves and the signal strength-height curves were correlated with duct strength and horizontal index of refraction gradient.

A81 Index of Refraction Data Procurement and Reduction (Microwave)
Hoidale, G. B.
Missile Geophysics Program WSPG Prog. Report No. 3
Feb 57

The need for a systematic study of the refractive index of the atmosphere has lead to the adoption of several observing systems. A summary of the reduction methods and data used to develop refractive index profiles for microwave electromagnetic energy at the White Sands Proving Ground, New Mexico, is contained in this report. A discussion of the accuracies and sensitivities of the current means of observation points out the usefulness of the data.

The observational methods described include radiosonde, wiresonde and tower samples of the meteorological parameters, and an airborne microwave refractometer for direct measure of the refractive index.

A82 Inhomogeneities in the Troposphere and Stratosphere
Gordon, W. E.
Cornell Univ. Astia AD 136-840

The effects of inhomogeneities on transmission are (1) signals from an unknown but powerful transmitter are detectable though weak in an aircraft beyond the radio horizon of the transmitter, and (2) communication from an aircraft to a terminal beyond the horizon is severely limited in range by the transmitter power requirements. The inhomogeneities produce fluctuations in apparent path length and hence in phase, angle and velocity measurements. In the lower troposphere, the fluctuations are significant where great accuracy is desired. This report describes a theoretical investigation of the effects of refractive index inhomogeneities in the troposphere and stratosphere as applied to (a) radio transmission problems in aerial reconnaissance and (b) radar tracking and guidance of airborne targets.

A83 Instrumentation for Determination of Radar Positional Errors Due to Propagation Through Non-Standard Atmosphere
Unknown author
Univ. of Kansas (4 vols.)
Aug 56

Equations for radar range, elevation, and azimuth angle errors caused by non-uniform atmospheres are developed both for spherically stratified and non-spherically stratified atmosphere. Emphasis is placed on range and elevation angle errors. An electronic analog computer solution for these errors is developed and applied. Range and elevation angle errors for a group of approximately 200 actual index of refraction profiles are computed by means of the analog computer and a statistical analysis of these errors by air mass classification is made. Four independent schemes of target location which are of sufficient precision to check a $\pm$ yard $\pm$ 0.1 mil radar are described and compared by means of the Volume of Uncertainty concept. This report includes four volumes with numerous graphs of actual data and results.

A84 Interpreting Refractive Index Profiles in Terms of Radar Coverage
Cowan, L. W.
ADC Forecast Center, Colo. Springs, Tech. Paper #3
Oct 55 AD 23 234

A catalog of radar coverage diagrams is presented. These diagrams are intended to give some quantitative measure of the effect of the location of the radar set under a variety of meteorological conditions which may be expected to occur in the atmosphere. Other variables which influence weather conditions are discussed briefly. These include equipment performance, target aspect, operator performance, surface reflections, atmospheric scattering and frequency.

A85 Investigation of Air-to-Air and Air-to-Ground Electromagnetic Propagation
Booker, C. R., et al
Cornell Univ. Elec. Engr, Interim Engr. Report IV
Apr 50

Scattering by atmospheric turbulence and refraction associated with elevated layers of non-standard gradient are investigated as they apply to air-to-air propagation. Different profile models are analyzed and much supporting mathematics is included. Tilted elevated layers are discussed. Results of several flight tests are reported.

A86 Investigation of Air-to-Air and Air-to Ground Electromagnetic Propagation
Unknown author
Cornell Univ. Elec. Engr., Final Report Part IV
Oct 51

This volume records the results of an investigation of air-to-air radio propagation. The experimental results consisting of field strength as a function of air craft separation on one or more frequencies (250, 1000, 3300 Mc.) are presented together with certain theoretical results based on standard and non-standard atmospheres. The estimate of the non-standard atmosphere is available since the experiment included certain meteorological observations from which the distribution of refractive index with height along the propagation path is deduced.

A87 Investigation of Air-to-Air and Air-to-Ground Experimental Data
Doherty, L. H.
Cornell Univ. Elec. Engr.
Dec 51

The propagation of radio waves in a horizontally stratified atmosphere of monotonically increasing refractive index is examined. The equations of geometrical optics, and of the Airy Integral representation of the field near a ray caustic are developed; and these two field representations, taken together, are shown to yield an adequate description of the radio frequency field. The equations developed are applied to different vertical profiles of index of refraction. The effect of elevated layers on propagation is considered.

A88 An Investigation of Anomalous Transhorizon Radio Wave Propagation Over Irregular Terrain
Cassam, R.
Cornell Univ. Center for Radiophysics and Space Research RS-35
Feb 62

The anomalous nighttime propagation of radio waves was studied at frequencies of 9100, 2800, and 840 Mc/s observed on the 108-km path from Rochester to Ithaca, New York. Previously proposed theories that explain anomalous propagation by ducting, reflexion or diffraction fail to explain the irregular behavior studied. Further radio measurements in the form of (1) sampling the 9100-Mc/s signal at 15 sites located along the propagation path, (2) height-gain measurements at 9100 Mc/s at the receiver site, and (3) swinging the 2800 Mc/s antennas 2° off the circle path, were undertaken in order to arrive at an explanation of the phenomenon. Finally, a theory based on the formation of elevated superrefractive layers situated over two lakes crossing the path is proposed to explain the anomalous propagation.

A89 Investigation of Atmospheric Refraction at Low Altitudes
Strand, K. J.
Maxwell AFB
Feb 53 AD 6452

Observations were made of the moon and of the Pleides at the Dearborn Observatory located on the western shore of Lake Michigan to obtain data on atmospheric refraction at low altitudes. Tabulated data are included for the exposure time and emulsion speed of the plates, the true altitude, the rate of change of refraction in arc seconds for each minute of arc change in the true altitude ($\Delta r/1'$), the probable error of $\Delta r/1'$, the observed value of $\Delta r/1'$ reduced to standard conditions according to the refraction tables in Astronomich.

A90 An Investigation of the Wave-Propagation Aspects of Surface-Based Surveillance Radar Performance
Gracely, F. R.
Air Force Operations Analysis Div., TM No. 39
Jan 53 AD 6122

A discussion is presented of factors which affect the general performance of radars. These factors include the operating efficiency of the equipment, topographical characteristics, station degradation, the nature of the target and its angle of presentation, and propagation conditions. The meteorological, field-intensity, and ray tracing aspects of the Radar-Propagation problem are considered. A comparative discussion is included of relative merits of the air-borne refractometer and other types of measuring equipment.

A91 Low-Level Overwater Refractive Index and Water Vapor Fluctuation Measurements
Crain, C. M.
Univ. of Texas EERL Rept. No. 5-22
Mar 57

This report presents an analysis of certain low level overwater refractive index data obtained at distances of 25 to 30 miles off the East coast of Florida by the Propagation Section of the Wright Air Development Center. It is not the purpose of the report to interpret the refractive index results in terms of meteorological conditions but to present merely a resume of the characteristics of the refractive index fluctuations obtained. A brief meteorological summary of the periods for which the data were obtained is also included.

A92 Meteorological Analysis of Selected Offshore California Refractive Index Profiles
Moyer, V. E.
Univ. of Texas EERL Rept. 6-09
Jun 55 AD71 929

Meteorological explanations are sought for the results of 12 daytime refractometer flights over areas centered some 150 nautical miles off the Coast of central California. Mesoanalyses of pressure, temperature, and mixing ratio, and the construction of vertical N-profiles from radiosonde data are used to examine the vertical variation of atmospheric refractive index over waters that normally induce the formation of marine ducts. The shape of the over-water profiles is found to be largely dependent on the mesometeorological synoptic situation, but not necessarily upon macrometeorological events. A characteristic Oakland radiosonde N-profile resembles most strongly the mean of a series of profiles observed by refractometer over offshore California waters, in that it frequently contains a radio duct in low levels. The radiosonde profile for Santa Maria contains sharp inversions as a principal characteristic, while that for Weather Ship 'Nectar' is characteristically standard. The use of mesoanalyses is found insufficient to account for minor variations in refractometer soundings. These are attributed to spatial and temporal variations in an air mass and to inhomogeneities in the properties of the underlying water. The concepts of vast homogeneous maritime air masses and of sharply discontinuous surface fronts over the oceans are seen to be unrealistic on many occasions.

A 93 Meteorological Aspects of Radio-Radar Propagation
Unknown Author
U. S. Navy Weather Research Facility
Jun 60 AD 243 191

This publication is a comprehensive reference in radio-radar meteorology and propagation. It includes basic theory on electromagnetic propagation and discussion of effects of absorption, interference, diffraction, reflection and refraction. Emphasis is placed on refraction, refractivity, and modified refractivity indices. Refractive index climatology is presented as well as aspects of ducting, radar holes, and range and elevation angle errors. Each effect is examined in several probable atmospheric situations. Methods to evaluate and predict radio-radar performance are presented for each of the propagation effects.

A94 Meteorological Aspects of Refraction and Propagation of Radar Waves
Unknown author
U. S. Navy Weather Research Facility
Jun 58

Task 31, "Meteorological Aspects of Refraction and Propagation of Radar Waves", was assigned the U. S. Navy Weather Research Facility for the purpose of developing new techniques for predicting the atmospheric refractive index. The operating units require refractive index information for evaluation of the effects of atmospheric conditions on radar performance.

This interim report presents some new aids for estimating refractive index conditions developed in the current research program of Task 31. It is believed that these aids together with a listing of selected references will be useful while the various phases of Task 31 are being completed.

A95 A Method of Forecasting the Refractive Index of the Elevated Layer
Naito, Keikichi
Cornell Univ. Elec. Engr. Research Rept. No. EE 280
AD 90 390

Considerations of polynomial expressions of horizontal coordinates were taken for the distribution of the refractive index profile. Linear expressions were valuable for the area of the order of 7 x 10^{14} sq. mi. Variations of the coefficients of linear expressions were investigated statistically to obtain certain relationships. The method of forecasting described is based on the relationships using predicted movements of the surface pressure patterns. A statistical test was made for the significance of the relationships with the F distribution as the verification method. The forecasting was fairly reliable for the height and the vertical gradient of the refractive index of the elevated layer and not so reliable for the thickness.

A96 Method of Investigating Radio Waves in the Troposphere under Large Angles
Zinichev, V. A.; Ryzkov, IU. A.; Iudin, O. I.
Morris D. Friedman, Inc., W. Newton 65, Mass.
May 61 AD 262 415

This is a discussion of an experiment at 3 cm wavelength to investigate the role of scattering by turbulent inhomogeneities in the troposphere over a 25 kilometer path.

A97 Methods of Predicting the Atmospheric Bending of Radio Waves
Bean, B. R.; Thayer, G. D.; Cahoon, B. A.
NBS Report 6056
May 59

Three methods of predicting the angular refraction, or bending, of radio rays by use of parameters which can be measured at the transmitting point are presented. The methods are checked by comparing predicted values of ray bending with calculated values obtained by numerical integration of some 77 diverse refractive index profiles derived from radiosonde observations. The three methods of prediction consist of a statistical regression of calculated ray bendings on the surface value of refractive index, an exponential model of refractive index height-distribution, and a method of improving the accuracy of prediction of the exponential model at small elevation angles by introduction of an additional parameter, the initial gradient of the refractive index at the transmitting point. The three methods are found to predict ray bending for elevation angles from zero to 90° and for heights from 1 km through the atmosphere with an r.m.s. error of prediction of no larger than 2.1 milliradians. Tables are included giving the statistical regression parameters for predicting both ray bending and elevation angle error from the surface value of the refractive index.

A98 Microwave Index of Refraction Fluctuations Associated with Certain Meteorological Situations in the East and Central U. S.
Wagner, N. K.
Univ. of Texas EERL Rept 6-17
Sep 56

This report is designed to present an analysis of certain of the airborne refractometer flights conducted by the Propagation Section of Air Force Cambridge Research Center under the direction of Lt. Harold Chapman during the late spring of 1956 in the northcentral and eastern portions of the United States. Some of the refractive index variations obtained during these flights can be described in general terms by making reference to previously published reports. Others, however, exhibit certain peculiarities not previously discussed and demand a more detailed analysis. Evidence is presented which more conclusively substantiates previous findings that frontal zones are not zones of smooth transition between two air masses. Further discussions reveal the capability of the airborne refractometer in delineating between converging and diverging air streams by measuring directly the relative moisture content variations and indirectly the differences in stability of the two air streams. Finally, an unusual set of refractometer data consisting of almost periodic variations is presented together with a few possible explanations.

A99 Microwave Potential Refractivity Distribution over the Gulf of Mexico
Hadeen, K. D.
Texas A. & M.
Jan 61 AD 249 243

The concept of potential refractivity was introduced with the aim of investigating the utility of this parameter as an aid in forecasting troposphere refractivity distributions. Two synoptic case studies were made of the potential refractivity distributions. The first case study shows the distributions of potential refractivity as a continental polar (cp) air mass invades the Gulf of Mexico. The second case study shows the distributions of potential refractivity as a tropical cyclone moves northwestward across the Gulf. The transition zone between air masses is clearly defined by the packing of the isopleths of potential refractivity. There appears to be a diurnal effect of solar insolation and terrestrial radiation on the distributions of potential refractivity isopleths over the coastal regions. The small changes in patterns of potential refractivity for 12-hour periods indicate that this parameter would be an aid in forecasting tropospheric refractivity distributions.

A100 Microwave Refractive Conditions Over WSMR, July Through Dec. 57
Hoidale, G. B.; Glenn, B.
WSMR TM 610, Progress Report NR6
Feb 59

The general microwave refractivity conditions over White Sands Missile Range were studied for July through December, 1957. Monthly mean profiles from the surface to 40,000 feet monthly mean surface diurnal variation graphs, and change profiles (1000-1400 Mountain Standard Time) for selected months in the lower 10,000 feet were drawn. The monthly change profiles were related to the general circulation.

A101 Microwave Refractive Index Profile for the Atmosphere over V from Radiosonde Data
Prosser, S. J.
WSPG Sup. to Tech. Report 18D
Jan 57

This report is a continuation of the work done in White Sands Proving Ground Technical Report 18D with special attention to the effect of relative humidity variations on refractivity in the layer above the ground. Realizing that the radiosonde does not accurately determine detailed refractivity changes with height, it was found that all major anomalies occurring in the profiles in Technical Report 18D were the result of erroneous meteorological data.

A102 Microwave Refractive Index Profiles for the Atmosphere Over WSPG From Radiosonde Data
Dixon, H. M.
WSPG Tech. Report 18b
Oct 56

The equation for refractivity in terms of meteorological parameters is discussed as well as the ray equations as applied to ducting. Refractivity profiles in the troposphere at White Sands Proving Ground obtained from daily radiosonde soundings are presented for a three month period during the Summer of 1956. On many days several soundings were made from the same location on the range but at various times, and in several cases simultaneous soundings were taken at several locations on the range.

A103 Microwave Tropospheric Study-Progress report for 1959
Dotts, W.; Miggantz, E. B.
U. S. Naval Missile Center, Point Nugu
Jul 61 AD 260 025

The Naval Missile Center has conducted refractive index measurements in the Southern California Coastal area over a period of 6 years (1954-1959). The refractive index profiles obtained over the 6-year period were analyzed to determine the frequency of occurrence of ducting, super-standard, and sub-standard layers. The results show that the probability of ducting layers occurring in the Southern California coastal area is high in July (100%) and August (88%), and low (below 50%) in April, September, November and December. The probability of sub-standard layers occurring in January to June and in October to December is low (below 10%) except in April (57%). The probability of super-standard layers occurring in January to March, and June to December is low (below 30%) except in August, where the occurrence is high (43%).

A104 On Models of the Atmospheric Radio Refractive Index
Bean, B. R.; Thayer, C. D.
N.B.S. Report 6025
Nov 58

This paper introduces two models of atmospheric radio refractive index which can be used to predict refraction effects from the value of the refractive index at the transmitting point. Both models offer considerable improvement over the four-thirds earth model. A new method of predicting radio ray refraction at very low initial elevation angles is introduced which utilizes both the initial value and the initial height gradient of the refractive index over roughly the first 100 meters above the earth's surface. This method, which is dependent only upon the first two radiosonde reporting levels or simple tower measurements of the common meteorological element, results in a considerable improvement of the values of ray-refraction predicted by the model.

A105 Moist-Term Refractivity as an Aid in Forecasting Tropospheric Refractivity Fields
Haragan, Donald R.
Texas A. & M., MS Thesis
Aug 60

This research initiates an investigation of the synoptic variations in the moist-term contribution to microwave refraction and the use of this parameter as an aid in forecasting tropospheric refractivity fields. Analyses have been made of both total and moist-term refractivity distributions for two meteorological situations in Alaska during February, 1954. The close correlation of the 12-hour changes in these two fields indicates that the moist term plays a predominant role in effecting total refractivity changes. Qualitative estimates of moist-term variations can be derived from temporal changes in temperature, dew-point temperature, and dew-point spread; since these are measures of vapor pressure, it follows that the latter is the most important contributor to the moist-term changes. It appears, then, that ability to forecast moist term refractivity is dependent upon increased knowledge of the variation and movement of atmospheric moisture patterns.

A106 Normal Tropospheric Propagation of Short Radio Waves Well Beyond the Horizon
Ring, R. M.; Carroll, T. J.
M.I.T. Lincoln Lab. Tech Rept No. 38
Feb 54

In this presentation the troposphere is idealized to be a linearly tapered layer of dielectric about 9-km thick. The radio field strengths propagated from a dipole situated in such an inhomogeneous atmosphere surmounting a curved perfectly reflecting earth are expressed as a sum of allowed modes. The complex eigenvalues of the modes have been calculated from the theory of the transition of bilinear modified index profile. Agreement of calculations with the median observed attenuation rates, absolute levels and height-gain behavior for frequencies of 50 Mcps, 410 Mcps, and 3,000 Mcps, is considered satisfactory at distances within, just beyond, and far beyond the horizon, out to about 400 miles. Comparison is made of the reflection for plane waves from inhomogeneous plane layers with tapers other than linear. The considerable underestimate of conventional airless 4/3 earth calculations of fields deep in the shadow of the earth bulge is attributed to the neglect of the downcoming waves resulting from coherent scattering by the air dielectric. Brief mention is made of the relation of these calculations to earlier "internal reflection" estimates, incoherent scattering by macroscopic turbulence, and the behavior of directive antennas.

A107 A Note on Selection of an Atmospheric Refractivity Model for Radar Range-Height-Angle Charts
Blake, L. V.
NRL Report 5626
Apr 61 AD 255-953

Research established the superiority of a negative-exponential model of the atmospheric radio refractivity vs. height function compared to the linearly decreasing refractivity assumed by the well-known 4/3-earth's radius method, of accounting for ray bending. However various values of the zero-altitude refractivity and the exponential constant may be used in the exponential model. For many purposes, such as plotting radar coverage on a range-height chart, a standard assumption for the atmospheric refraction, corresponding to fixed values of these constants, is desirable. Various factors relevant to selection of such a standard are discussed. A chart and table of ray-path range-height values are presented.

A108 The Oceanic Duct and its Effect on Microwave Propagation
Anderson, L. J.; Gossard, E. E.
U. S. Navy Electronics Lab. Rept. No. 305
Aug 52

In this report, the meteorological properties of the oceanic duct are examined in terms of recent theoretical relations obtained by other workers and the resulting refractive-index profiles are compared with those actually observed in order to confirm the validity of the theory. The principal virtue of the relations developed is that they enable the temperature and humidity profiles (and therefore the refractive-index profile) to be obtained from sea-surface temperature and a standard meteorological observation taken at one level (20 to 50 feet) above the surface. Having established the refractive index profile from these measurements, one can predict its effect on the propagation of electromagnetic energy by application of leaky waveguide propagation theory.

A109 Power Spectra Evaluation for Selected Airborne Microwave Microwave Refractometer Readings
Edmonds, F. N., Jr.; Bostick, F. X. Jr.; Gerhardt, J. R.
Univ. of Texas, EERL 6-24
Aug 58

Fifteen samples of tropospheric index of refraction fluctuations have been analyzed statistically to give a description of the fluctuation field which is then interpreted in terms of current theories for the production of these fluctuations. The samples or slots were measured with an airborne microwave refractometer over Camp Carson, Colorado, at altitudes ranging from 6500 to 20,000 feet above mean sea level. The analysis used improved equipment and techniques developed at EERL and yielding a power spectrum, an amplitude distribution plot and a running rms for each sample which are presented in Appendix I.

A mathematical representation of the variation of the amplitude of the variations with frequency and with altitude has been obtained for the power spectra of the samples. This representation supports the universal equilibrium theory rather than the mixing-in-gradient theory for the production of the fluctuations by turbulence; it questions the use of Gaussian, exponential and molified Bessel correlation functions to describe the fluctuation field, and it emphasizes the critical role of meteorological factors in determining this representation.

A discussion of the effects of molecular diffusion, tests for determining whether correlation functions can be associated with a given power spectrum, an investigation of how representative the 15 samples are of average conditions in Southeastern Colorado, and a meteorological discussion of the variation of power spectra with altitude are attached as appendices to this report.

A110 Precision Tropospheric Radio Refraction Corrections for Ranges from 10-500 Nautical Miles

Bauer, J. R.; Wilson, F. A.
M.I.T. Lincoln Lab. #336-0015
Feb 61 AD 252 572

Computed elevation angle and slant range refraction corrections as well as true target height and polar angle as measured from the center of curvature of the earth are tabulated as functions of the two basic radar outputs: measured slant range and elevation angle of arrival. The mean exponential model of atmospheric refractive index described previously by Bauer, Mason and Wilson is assumed. Tables of computed quantities are given in the measured slant range interval 10-500 nautical miles and elevation of arrival region 0-90 degrees. Computational errors in target height and true slant range are less than a few feet at all ranges while errors in angles are of the order of 10^{-3} degrees or less. At heights below the ionosphere ($h \lesssim 60$ km) these results will be applicable at all radio frequencies. For heights extending from sea level through the ionosphere the full utility of the tables will be confined to frequencies above a few kilomegacycles.

A111 A Preliminary Climatology of Refractive Index Layer Characteristics I. Southwest Ohio and the Washington Coastline
Moyer, V. E.; Gerhardt, J. R.
Univ. of Texas EERL 6-26
Nov 58 AD 160 841

In an effort to establish forecasting systems involving the effects of atmospheric refractive index distribution on microwave propagation, a number of climatological and synoptic-climatological surveys of refractive index patterns have been made using radiosonde data. Results of preliminary statistical evaluations of the heights, thicknesses, and intensities of significant atmospheric layers are presented over two geographical areas, southwestern Ohio, and over the offshore waters of the state of Washington. These evaluations are given in terms of frequency distribution accompanied, where possible, by gross correlations with synoptic-scale meteorological, climatological, and geographical properties.

A112 A Preliminary Climatology of Refractive Index Layer Characteristics II. Southern California Coastal Areas
Wagner, N. K.
Univ. of Texas EERL 6-28
May 59

A total of 799 refractometer index of refraction profiles obtained in the Southern California coastal region over roughly a five-year period are analyzed in an attempt to establish a preliminary index of refraction layer climatology of this area. Frequency distribution showing the monthly occurrence of various layers and the variations in the height, thickness and strength of these layers are presented. The summer months are found to have a ducting layer frequency of occurrence near 100% and a substandard layer occurrence near 40%. The winter months are practically free of substandard layers, but ducting layers are still present about 65% of the time. The major non-standard layers are shown to be closely related to large scale atmospheric flow patterns and a basis for layer forecasting is briefly presented. A comparison between radiosonde and refractometer ducting layer frequency of occurrence data suggests that the radiosonde is incapable of detecting approximately 15% of the significant ducting layers which occur in the atmosphere.

A113 A Preliminary Study of the Variations in Refractive Index Over a 5000-Foot Height Interval Above the Earth's Surface
Crain, C. M.; Deam, A. P.; Gerhardt, J. R.
Univ. of Texas EERL #53
Jun 51

This report gives results of airborne refractometer measurements made in April, 1951, over the Atlantic Ocean and the New Jersey shore area in the vicinity of Lakehurst, New Jersey. The refractometer was carried aloft in a Navy Type-M airship. Measurements were made of both rapid fluctuations of refractive index at various altitudes from 250 to 5000 feet and the change in mean refractive index with height. Measurements were made also of air temperature fluctuations.

A114 A Preliminary Synoptic Analysis of the Atmospheric Refractive Index Climatology of Alaska
Moyer, V. E.
Univ. of Texas EERL Rept No. S-06
Feb 55 AD 58 923

This research has initiated a study of the radio climate of Alaska. Of the variety of possible analytical techniques, a synoptic approach was chosen in an initial attempt to determine the correlations between regional variations of the refractive index and regional variations of the meteorological elements known to affect the index.

Two varieties of regional maps were constructed from aerological data to determine the daily variation of the horizontal distributions both of the lapse with height of the microwave refractive index and of the absolute values of this index at the 850-millibar level. In addition, meteorological explanations were sought for the occurrence of two radio-duct gradients detected by airborne refractometer flights over the Alaskan mainland.

The device of constructing horizontal isopleths of the regional distribution of the mean refractive index in the 1000-850 millibar level seem to be more useful in this sense, because this parameter is more sensitive to daily change than is the former. Finally, the synoptic meteorological events that accompanied formation of the observed radio ducts are shown to be at least contributory factors in their formation.

A115 Present Methods Used at APGC of Correcting TSPI for Electromagnetic Propagation Errors
Landry, P. M.
Presented at IRIG
Sep 60

This is a short thermofax paper covering already reported material.

A116 Propagation Errors in Radio Location Systems
Mallinckrodt
AFMTC Patrick AFB, Tech Rept #4
Jun 51

Present radio-location systems all depend on measurements either of the angle of arrival of a wave, or of the time delay of a wave, or of some combination of the two. Both of these types of measurements are affected to some extent by any variation in velocity of propagation between station and object. The earliest radio location systems did not require compensation for these effects since inherent equipment errors were generally considered greater than the systematic propagation errors. However, the inherent precision of many modern systems is such that propagation effects may become the dominant source of error unless compensated. These questions therefore aries: (1) how large are these systematic propagation errors relative to the random errors, (2) what type of system is the least susceptible to errors of this type, and (3) how best to correct for the errors of propagation in a given system. This report deals with these three questions, comparing a single station system measuring one range and any two angles with a three station baseline system measuring ranges only.

A117 418 Mc Propagation Measurements over the Cedar Rapids--Quincy Path
Decker, M. T.; Jones, H. B.
N.B.S. Rep. No. 3520, Supp. III
Jun 55

The transmitting, receiving and recording facilities used in propagation measurements made at 418 Mc during the period May to December, 1951, over the 133.9-mile Cedar Rapids--Quincy path are described. The discussion of the received signal power data includes an analysis of variations in instantaneous signal level, as well as analysis of diurnal and seasonal variations in hourly median signal levels.

A118 Propagation of Radio Waves Through the Troposphere and Ionosphere
Counter, V. A.
Lockheed Corp.
Dec 56 AD 211 504

The active role of Lockheed Missile Systems Division in the research and development of missiles and associated weapon systems has necessitated the establishment of a program for the study, analysis, and prediction of deviations of radiowaves from free-space propagation. These deviations significantly affect the radio waves that may be used for control, command, guidance, telemeter, detection, tracking, arming, or fuzing of these systems. This unclassified research has been supported by three classified projects at Missile Systems Division as well as by General Research funds. This is a preliminary report presenting the theoretical approach and some of the numerical results to date. The work is continuing and more complete numerical results will be presented in subsequent reports.

A119 Propagation of Short Radio Waves
Kerr, D. E. (Editor)
McGraw Hill
1951

This summarizes the state of knowledge of the field at the end of the second World War. Contributions from the M.I.T. Radiation Laboratory figure heavily.

A120 Radar Elevation Angle Errors and Refraction Corrections
Cramond, Wallis R.; Leeman, James E.; Thorn, Donald C.
Univ. of New Mexico EE-79
Sep 62 AD 287 231

This report gives the results of the analysis of 474 radar elevation angle measurements, The Fannin-Jehn, Rainey-Thorn, and Bean-Cahoon refraction correction methods are compared. Computed refraction corrections were obtained based in most cases on refractivity profiles determined from rawinsonde observations. Errors in the refraction correction from various sources are discussed as is the variation of total refraction with time of day and season. It is concluded that more reliable and time coordinated meteorological data as well as more accurate radar observed angles are needed to study and justify any detailed refraction correction method such as the Fannin-Jehn and the Rainey-Thorn methods.

A121 Radar Elevation Angle and Range Errors in a Representative Air Mass
Fannin, B. M.; Jehn, K. H.
Univ. of Texas, EERL NR7-01
Jun 54

An investigation is made of radar angular, range and velocity errors resulting from the travel of microwaves through the atmosphere. Errors resulting from various mean or representative air masses are evaluated and the effects of various radio ducts and substandard layers are also considered. Included in the radar systems discussion are conventional radars, baseline radars and doppler systems.

A122 A Radar Refraction Correction for Symmetric or Non-symmetric Tropospheric Index Distributions
Rainey, R. J.; Thorn, D. C.
Univ. of New Mexico EE-43
Feb 61 AD 287 484

This paper approaches the mathematics of the refraction problem from the basic differential equation of the ray path in a variable-velocity type of medium. This approach differs from the usual approach in that Snell's Law for a spherically symmetric medium is introduced as a special case instead of being assumed at the outset as is most often done. The concept presented here emphasizes the true refraction mechanism, the gradient of the refractive index along the ray path irrespective of the symmetric properties of the medium. In order to emphasize the source of ray theory, which is so widely used in refraction analysis, the radar refraction problem is initiated from an assumed field solution of Maxwell's equations. The basic ray equation is then adapted to the general non-symmetric atmosphere and specialized to a distribution characterized by regions of constant gradient. The concept is applied to the spherically symmetric atmosphere to facilitate a detailed examination of the approximations made in the development of the method as well as to indicate the applicability of the concept to this widely used model.

A123 Radio Climatology of the WSPG Area
Prosser, S. J.
Electromagnetic Radiation Through the Atmosphere PR NR 5
Apr 58

A study is made of the atmospheric refractive effects upon microwave propagation in the vicinity of White Sands Proving Grounds. A general survey of the Radio Climatology provides the basis of the study, while B and N profiles from average monthly radiosonde data picture the average conditions. Also included in the report is a section on obstacle gain.

A124 Radio Meteorological Data Available as of Apr. 1, 1958
Riggs, L. P.; Bean, B. R.
N.B.S. Report 5565
Apr 58

Government agencies engaged in radio-climatology met on January, 1958, at the Boulder Laboratories of the National Bureau of Standards and agreed upon:
(1) Non-overlapping geographical coverage in climatological calculations,
(2) Uniform calculations of basic parameters and presentation of data,
(3) Free exchange of data
The report lists all points involved under listing 1 and 2 that were unanimously agreed upon. Also, a list of radio meteorological data available by laboratory is given.

A125 Radio Meteorology and Climatology of the Eastern North Pacific
Holden, D. B.; Gossard, E. E.; Hopkins, R. U. F.
U. S. Navy Elec. Lab, San Diego, RP No. 966
Apr 60

In this report the radio meteorology and climatology of the northeastern Pacific are analyzed in terms of the probability of greatly extended propagation ranges at very high frequency. Seasonal charts of frequency of occurrence of elevated trapping layers are presented for the north Pacific.

A126 Radio Propagation Study Interim Engineering Report
Herman, E.; Rentschler, M.; Russell, W.; Dodds, B.
AD 234 345

This report contains a survey of the effects of the earth and its atmosphere (to an altitude of 750 km) on radio waves in the frequency range of 30 mc to 100 kmc. The effects of terrain considered are diffraction and reflection. The atmospheric effects are divided into sections on the troposphere; the ionosphere not including the auroral region; the auroral region of the ionosphere; and meteor trail effects. Under these sections absorption, reflection, scattering, and time variations (including seasonal variation and fading) are considered.

A127 Radio Refraction in a Cool Exponential Atmosphere
Bauer, J. R.; Mason, W. C.; Wilson, F. A.
Lincoln Lab Tech Rept 186(U)
Aug 58 AD 202 331

Equations are derived for computing the height of a radar target as a function of observed slant range and angle of arrival for the case of propagation through a spherically symmetric nondispersive atmosphere with an arbitrary refractive index distribution. This method is applied to calculate propagation through a troposphere that obeys the exponential law. The results are then compared to the calculations based on the 4/3 earth's radius principle. Interpolated values of height vs. range for the exponential model are tabulated in 10 n.mi. intervals of range to a maximum range of 360 nmi., for elevation angles of 0° to 90°, to a maximum height of 100,000 ft. These values are then compared to measured refractive index soundings.

A128 Radio Refraction in the Free Atmosphere
Hooper, A. H.; Taylor, A.P.
Meteor. Research Comm. Rept. MRP 1021; SC 1/121
AD 139 540

The effect of refraction on the height of an object calculated from radar measurements of slant range and elevation is determined, with particular reference to the reflectors carried by free balloons used for wind finding by the Meteorological Office. The true height of an object is expressed as a function of its angle of elevation as observed from a point on the ray path and numerical solutions are obtained for a particular distribution of refractive index. The effects of departures from this refractive index structure are discussed and the conclusion is reached that a set of standard corrections is probably adequate for meteorological purpose.

A129 Radio Wave Propagation
Burrows, C. R.; Attwood, S. S.
Academic Press, Inc. Tech Rept. Comm on Prop. of the NDRC
1949

This book gives a wide variety of papers, theoretical, expository, and experimental. They are mostly wartime reports which were declassified at the end of the war.

A130 On Radio Wave Propagation in an Homogeneous Atmosphere
Wait, J. R.
N.B.S. Report 6035
Aug 59

A self-contained treatment of the theory of radio waves in an inhomogeneous atmosphere is given. The refractive index is assumed to vary with height above the earth in a monotonic fashion. Variation according to an exponential law is used for illustration of general principles. For this case, rigorous series formulas are developed for the distance to the horizon for an elevated point in the atmosphere.

A131 The Rapid Reduction of Meteorological Data to Index of Refraction at Radar Frequencies
Anderson, L. J.; and Abbott, F. R.
Navy Electronics Lab, San Diego, Calif. Rept. WP-8
Dec 43

In studying the refraction of radar radiation in the lower atmosphere it is necessary to determine the index of refraction under innumerable sets of meteorological conditions. This paper presents a method which is rapid and at the same time accurate enough to detect the relatively small changes that occur.

A132 Ray Tracing on the IBM650
Gardner, L.
Columbia Univ.
Jun 57 AD 215 643

A method is presented for using a minimum 2000 word IBM-650 to trace rays in an inhomogeneous medium having one irregular boundary. Provision has been made for velocity discontinuities in both dimensions which further complicate an already involved machine computation. Logical operation outnumber numerical operations, and hence the approach has been adopted of programming the former in basic language and using floating point subroutines for the latter. The paper consists of a short explanation of the problem together with presentation and discussion of the logical flow charts. Instructions for operating and program listings are included.

A133 Ray Tracing Picture of Radio-Wave Propagation in Arbitrary Atmosphere
Wong, M. S.
Wright ADC, A.F. Tech Report No. 6631
Jul 51

A REAC differential analyzer is used for ray tracing based on a development following Hartree, Michel and Nicolson. The refractive index, n, and its gradient are arbitrary functions of height in a given location. An arbitrary atmosphere is represented by a number of height profiles of the refractive gradient measured at various locations together with a linear interpolation of these profiles for intermediate locations. Ray families are presented for spherically stratified atmospheres and for an atmosphere represented by three such profiles. Conclusions are arrived at with respect to radio holes and antiholes, and their relative occurrence over land and ocean.

A134 Refraction Correction and Height Accuracy for Radar Height Finders
Schipper, R. J.,; Niemi, Paul, et al.
AVCO Mfg. Corp. Cincinnati, Ohio, Rept No. EW 9929-TN-04-60
Sep 60 AD 319 110

The phenomenon and effects of refraction on the accuracy of Radar Height Finders is discussed, and the means of correction utilized in the AN/FPS-26 RADAR HEIGHT FINDER. Mathematical relationships are derived and ray tracing techniques are analyzed and employed to obtain the amount of bending encountered by the radar wave as it travels through various atmospheric profiles. A variable factor, dependent on the radar elevation angle and surface refractivity value, is derived and applied to the radar height equation to compensate for the effect of refraction. The method of instrumenting the height equation into the AN/FPS-26 is discussed. Theoretical errors associated with the standard 4/3 correction and the improved accuracy inherent in the new refraction correction method as employed by AVCO in the AN/FPS-26 are supported by actual flight test data. Methods of selection of the proper variable factor, or profile, for refraction correction to be instrumented into the Radar Height Finder are investigated. Specific conclusions are developed and several additional studies in the area of atmospheric refraction of electromagnetic waves are recommended.

A135 Refraction Corrections for Radar-Optical Systems
Hanson, F. S.
White Sands Proving Ground Tech Memo No. 218

A procedure is given for calculating atmospheric refraction errors of radar-optical systems from aerological data. The differential refraction error between radar and optics may be calculated by a directed method. This involves a simple numerical integration of the moisture profile. The differential refraction error, so obtained, represents the distance of a radar target below the cross hairs of its optical boresight.

An analysis of the precision and bias of the method is included. This procedure appeared to have sufficient accuracy for the current application at WSPG.

A136 Refraction Errors in Space Positioning of High Flying Objects
Anderson, L. J.; Trolese, L. G.; Hughes, L. R.
Smyth Research Assoc. Rept. SRA-74
Nov 58 AD 148 887

The report investigates the possibilities of making observations of radio ray bending through the troposphere and through the ionosphere to determine random refraction errors in radar elevation angles. Since the refractive effects are largest at low elevation angles, and decrease rapidly with increasing elevation angle, the experimental equipment used must be capable of good elevation resolution at low angles. The most practical way to make these measurements was found to be with a sea interferometer. Discussion is given to the sources of radio waves and to the location of the observation sites for these studies.

A137 The Refractive Correction Developed for the AN/FPS 16 Radar at White Sands Missile Range
Pearson, K. E.; Kasparek, D. D.; Tarrant, L. N.
WSMR Tech Memo 577
Nov 58

This report presents a simple refraction correction for radar and elevation angles which was developed specifically for AN/FPS-16 radars at White Sands Missile Range, New Mexico. This correction is based upon an observed index of refraction at the radar site. Evaluation of data utilizing the observed surface refractive index correction indicated that it removed about 90 percent of the refractive error in elevation angles.

A138 The Refractive Index of the Atmosphere as a Factor in Tropospheric Propagation far Beyond the Horizon
Gray, R. E.
IRE Nat'l Conv Record Part I, pp 3-11
1957

The monthly median path loss is shown to be a function of the average surface values of refractive index of the atmosphere on the transmission path. Extreme values of path loss are evidently due to abnormal vertical gradients of refractive index. Curves are given showing the relation found on various paths between transmission loss and refractive index. It is concluded that estimates of monthly median transmission loss over a path may be made on the basis of a knowledge of average monthly surface values of the index of refraction.

A139 Refractive Index Distribution Associated with "Blocking Action" Over Northern Portions of North America
Jehn, K. H.
Univ. of Tex. EERL Rept. 7-15
Jun 58

Microwave refractive index distributions in the lower atmosphere through the various stages of development of a "blocking high" over northern North America are presented by means of surface and 850-mb analyses, along with vertical atmospheric cross-sections.

A140 Refractive Index Distribution Associated with the Texas Gulf Cyclone and the Central U. S. Cold Outbreak
Jehn, K. H.
Univ. of Tex. EERL Rept. 7-10
Apr 57 AD 154 626

Microwave refractive index distributions in the lower atmosphere through the various stages of development of the winter Texas-West Gulf cyclone and the midwest cold outbreak in winter are presented by means of surface and 850-mb analyses along with vertical atmospheric cross section. The refractive index distribution study also included diurnal variations. Typical examples of these situations were analyzed to produce composite distributions of refractive index representative of 4 or 5 actual cases. Although the relationships between refractive index distributions for different seasons and geographical areas were previously reported, the previous findings are directly applicable to the current analyses. For example, a surface value of refractive index of 300 N-units in the vicinity of Columbia, Missouri, in either of the winter situations analyzed indicated, for a target at 30,000 ft. MSL, a radar elevation angle error (expressed as $\Delta\alpha$ tan ($\Delta\alpha$ in radians)) of approximately 120×10^{-6} for an elevation angle greater than 30°. However, the same $\Delta\alpha \tan\alpha$ of 120×10^{-6} would apply in winter in the vicinity of Lake Charles, Louisiana, for a surface value of refractive index of 310 N-units for a target at 50,000 ft. MSL seen with an elevation angle of 3°. The values of the diurnal variation and standard deviation of refractive index at the various locations gave an indication of the expected variability of the error angles to be expected in different parts of synoptic patterns.

A141 Refractive Index Profiles and Associated Synoptic Patterns
Arvola, W. A.
Navy Electronics Labs, San Diego, Calif. NEL Rept 793
1957 See Periodical P143 AD 143 768

A study is made of meteorological conditions associated with synoptic patterns passing over the Middle West leading to super-refractive index profiles. The signal strength for a 71.75 mc TV-link in Illinois is related to the refractive index profiles.

A142 The Refractive Index Structure of a Cumulus Boundary and Implications Concerning Radio Wave Reflection
Plank, V. G.; Cunningham, R. M.; Campen, C. F. Jr.
Geophysics Res. Directorate AFCRC
Mar 57

Refractive index measurements made during an aircraft pass through cumulus have been analyzed for the details of index fluctuation at the cloud boundary. The microstructure is described and an explanation suggested. A restrictive estimate of boundary region reflectivity is obtained, using current theory.

A143 Refractometer Measured Tropospheric Index of Refraction Profiles, Volum I
Crain, C. M.; Moyer, V. E.
Univ. of Texas, EERL Rept 6-02
Feb 53 AD 13 269

Profiles are presented which were made from measurements with air-borne, direct reading, microwave refractometers during flights in August off the coast of Northern Washington, in late July and early August over southern Ohio, and in mid October off the California coast near San Francisco. A qualitative weather summary is presented for each flight. The refractometers were mounted in C-46, B-17, or B-25 aircraft; the metering circuit design permitted measurements on a 50-, 100-, or 200- refractive index (N) unit range anywhere over a 400 n-unit range. The rate of ascent and descent was between 500 to 1000 ft/min at indicated air speeds of 120-150 mph for the C-46 and 170-200 mph for the B-17 and B-25.

A144 Refractometer Measured Tropospheric Index of Refraction Profiles, Vol. II
Crain, C. M.; Moyer, V. E.
Univ. of Texas, EERL Rept 6-03
Jul 53 AD 22 159

Curves are presented of data obtained with air-borne, direct reading, microwave refractometers for 9 flights between Nov. 11 and 21, 1952, off the East Long Island Coast, 16 flights between Dec. 4 and 17, 1952, off the New Jersey Coast, and 13 flights between Sept. 16 and Oct. 1, 1952, over southwest Ohio. A graphical summary is included of about 700 other index-of-refraction profiles which shows the intensity distribution of the observed elevated layer for each sounding location. Differences in time or position within a sounding area are not distinguished.

A145 The Requirement for Refractive Index Observations in Radar Evaluation Programs
Metcalf, D. F.
Univ. of Texas, EERL Rept 6-10
Jul 55 AD 71 930

A discussion is presented of the importance of utilizing vertical gradients of atmospheric refractive index as the principle criteria in detecting nonstandard behavior in radar evaluation tests.

A146 A Review and Evaluation of the Radar Propagation Error Problem
Fannin, B. M.
Univ. of Texas, EERL Report 7-03
Nov 54

This report contains a review and evaluation of results reported by other investigators pertaining to propagation-induced radar errors. The problem is divided into six subtopics that are treated separately, these subtopics being elevation-angle errors, angular errors in the horizontal plane, range errors, errors for triangulation systems, doppler errors, and attenuation. In addition, a summary of the results obtained by the University of Texas group under the present contract with the St. Louis Ordinance District is included. In light of the present state of knowledge of propagation effects, as presented in the first portion of this report, remaining problems that need solution are discussed in a later section. Some of the apparent difficulties likely to be encountered for various approaches to some of the problems are pointed out and recommendations are made concerning the lines along which future effort should be directed.

A147 A Search for Means to Detect Distant, Low-Flying Aircraft
Pike, E. W.
Lincoln Lab., M.I.T., Tech. Rept. 161
Jul 57

Possible methods of detecting, by a ground-based observer, an aircraft 40 miles distant, about 100 feet above the terrain and about 1000 feet below the observer's mask are examined. Only one of 18 physically possible systems studied is reported to have even marginal operation possibilities. The systems studied were based on the following type interactions: static gravitational force; vector gravitational force, scattering of cosmic rays, sound generated by lift forces, engine and propeller noise, ferromagnetic fields, etc.

A148 Signal Fluctuations in Long Range Overwater Propagation
Ament, W. S.; Katzin, M.
N.R.L. Report 3629
Mar 50

Measurements of overwater propagation in the Pacific on 3 and 9 cm between airborne transmitters and fixed receivers are reported. Within the horizon, the direct and surface-reflected rays formed the usual interference patterns. Beyond the horizon, the 3-cm signal always behaved in general accord with normal-mode theory, the attenuation rate averaging 0.5 ± 0.2 decibels per (nautical) mile. In roughly the first 30 miles past the horizon, the 9-cm signal had a height-gain and an exponential decay rate (0.9 to 1.9 decibels per mile), both reasonably dependent on measured duct strength. On 9 cm only, all greater ranges comprised a "turbulent region", where a new, lower attenuation rate prevailed, averaging 0.17 ± 0.05 decibels per mile, and where there was no average height-gain. Turbulent-region signals were approximately Rayleigh-distributed and the autocorrelation of their fluctuation vanished in, at most, 1.5 seconds. The turbulent-region signal undoubtedly was due to scattering by some high-altitude atmospheric mechanism.

A149 A Simple and Accurate Correction for the Refraction Errors of Electronic Tracking Systems
Mallinckrodt
AFMTC Patrick AFB, Tech Rept 36
Jun 52

It is the purpose of the present report to consider the question: "How good is a standard correction? Is it adequate relative to other instrumentation accuracy limitations, or will it be necessary to compute the required correction each day on the basis of actual meteorological soundings along the transit path?" Actual day to day variations in the required refraction correction as determined by meteorological soundings over Patrick Air Force Base, Florida, are examined with this question in mind, and it is concluded that a standard correction plus a second order term involving the index of refraction measured at ground level only represents an adequate correction in the sense that the probable error of the correction estimated on this basis is less than that of any presently conceived radio wave instrumentation.

A150 Simple Methods for Computing Tropospheric and Ionospheric Refractive Effects on Radio Waves
Weisbrod, S.; Anderson, L. J.
Smyth Research Assoc. San Diego, Calif. Rept 68
Sep 58 See Periodical P150

This paper describes a very simple and accurate method for computing ionospheric and tropospheric bending. The only assumptions are that the refractive gradient is radial and that the refractive profile can be approximated by a finite number of linear steps whose thickness is small compared with the earth's radius. The assumptions are readily justifiable in all practical cases. Since there are no limitations on the angle of elevation and the shape of the refractive profile, the method has a wide application. This method is extended to cover other refractive effects as retardation, doppler error and the Faraday Rotation.

A151 Some Examples of Exponential Refractivity Distribution
Waldron, C. G.
U.S.N. Postgraduate School, Monterey, Calif.
1960

Recently, exponential models of refractivity have been devised by several investigators to replace the linear "Standard" refractive atmosphere. In this study, average values of N are evaluated from the data at the mandatory radiosonde levels up to 25 mb, and mean coefficients C_i satisfying $N_{i+1} = N_i e^{-Ci(Zi+1-Zi)}$ have been evaluated for a group of eight mid-latitude stations, and for the entire winter season of 1958-59. The coefficients C_i, plotted as functions of the height of the i-th layer-center, possess certain characteristic features in common at all stations.

A152 Some Information Theory Aspects of Propagation Through Time Varying Media
Feinstein, J.
IRE Conv. Record, Part 1, pp 87-97
1954

The channel capacity of a communications system which utilizes wave propagation through a time varying medium such as the ionosphere or troposphere is evaluated in terms of the statistical properties of the medium and of the noise. The signal fading in such a system reduces the capacity. Information theory concepts are broadened to include the possibility of multiple reception at spaced receiving sites, and the consequent increase in theoretical channel capacity is computed as a function of the number of such sites. Current practices in the use of diversity reception and directional antennas are examined in the light of these results.

A153 Some Meteorological Aspects of the Radio Refractive Index
Horn, J. D.; Bean, B. R.; Riggs, L. P.
NBS Boulder Labs, Rept. 6066
Aug 59

A reduced-to-sea-level expression for the radio refractive index has by effectively removing altitude dependence, facilitated preparation of the world-wide contour maps of refractive index. Basic maps of average values of refractive index for summer and winter and for an annual range are given.

When used for studies on a synoptic scale, this parameter is a sensitive indicator of departures from average atmospheric structure caused by tropospheric storms. The morphology of a synoptic disturbance is shown by a series of refractive index surface maps and vertical cross-sections.

Studies of atmospheric refraction of radio waves have shown than an exponential decrease of refractive index with height is more representative of the true structure and yields more reliable estimates of refraction effects than the linear decrease assumed by the effective earth's radius theory. A modified form of refractive index, called potential refractivity, which is exponentially related to height, has been developed. Its use in refractive index air mass analysis and synoptic work is shown. An air mass profile study of frequently-occurring air mass types based on potential refractivity is given.

Results from studies on the prediction of refractive effects on radio wave propagation are given. Graphs showing the statistical relationship between the surface value of refractive index and elevation angle error or total atmospheric bending of radio rays are presented.

A154 Some Problems in Long Range Propagation of Microwaves in the Troposphere
Vysokovskie, D. M.
Academy of Science USSR, AFCRC-TR-59-151
1958 AD 216 238

This is a survey of the theoretical and experimental work on long range transmission of microwaves. Data is presented about turbulent heterogeneous flow in the troposphere and the fundamental transmission theory of radio waves in a heterogeneous medium is discussed along with other theories of long range propagation. Data is presented about the fluctuations of amplitudes and phases of long range fields; an attempt is made to classify available experimental data and certain problems are considered in the calculation of long range communication systems utilizing the long range propagation of microwaves in the troposphere.

A155 Spurious Echoes on Radar, A Survey
Plank, V. G.
A. F. Cambridge Research Center, Geophysical Res. Paper 62
May 59 AD 215 470

Radar echoes that are received from a sensibly clear atmosphere are commonly called "Angels". In this paper the various types are described and the probable causes discussed. Also considered is the nature of signals from extraterrestrial sources.

A156 Statistical Analysis of Selected Tropospheric Microwave Refractive Index Recordings
McClure, R. M.; Smith, H. W.
Univ. of Texas, EERL Rept 6-22
Jul 57

Selected samples of microwave refractive index recordings taken with a Crain refractometer have been analyzed for the purpose of further examining the statistical nature of the recorded fluctuations. Although the samples were chosen with a view to minimizing the large scale effects, the magnitude of the large scale changes was so great compared with the small scale changes that only by filtering could the small scale changes by analyzed. For the longest sample available covering ranges up to 30 miles, the RMS of the fluctuations continued to change as a function of sample length indicating that the refractive index fluctuations do not represent statistically stationary data.

A157 Studies in Tropospheric Propagation
Unknown author
Univ. of Texas, EERL Rept 6-41
Dec 60 AD 251 286

This report briefly summarizes and reviews the major accomplishments reported in a series of technical reports published under contract AF 19(604)-2249 by EERL at the University of Texas. The investigation involved a variety of problems in the area of radiometeorology and tropospheric propagation. The technical reports and journal publications resulting from this investigation are listed.

A158 Study of Propagation Characteristics of the Atmosphere--Final Report
Unknown author
Univ. of Texas, EERL Rept 6-40
Oct 60 AD 251 287

Wave propagation through a tropospheric layer of anisotropic turbulence was studied by comparing both the wave theory (microwave optics) approach, applicable to homogeneous layers, and the single scattering (first Born approximation) approach applicable to homogeneous turbulence. The first order correspondence of wave theory and single scattering theory results for the homogeneous layer (at least for the normal incidence) indicated that a single scattering theory approach can be expected to give valid approximations of the propagation effects produced by nearly homogeneous layers. The single scattering theory formulation of turbulent layer problems is more complex due to the mathematics necessary to describe the turbulences; the single scattering concepts should be just as valid as for the homogeneous layer. The diffracting screen approach offered a convenient means of interpretation of the propagation effects produced by a turbulent layer.

A159 A Study of Propagation Conditions at Vero Beach
Hines, C. A.
Apr 57 AD 118 200

This report presents a summary of the results of a study of the degraded propagation environment of the eastern coast of Florida. The data were taken on 22, 23, 24, and 25 May 1956.

A series of refractive index measurements was made at altitudes from 5 feet to 15,000 feet above the surface of the sea. These measurements yielded vertical profiles and micro-fluctuation data. These data were taken so as to facilitate correlation with signal strength information taken on horizontal flights over the ground-based transmitter at Vero Beach out to and beyond Grand Bahama Island in a southeasterly direction. Tentative conclusions are made based on the measured data. An approach to the hitherto unexplained propagation anomalies described in the text is advanced.

A160 Study of Refraction Errors in Radar Propagation
Dixon, H. M.
White Sands Signal Corps Agency Tech Rept. 18A
Apr 56

The refraction of radar propagation by a spherically stratified variation of atmospheric refractive index was studied by the use of Fermat's principle, assuming only those variations of index of refraction that would be produced by varying temperature, pressure, and water vapor pressure. An arbitrary rough variation of index of refraction with altitude was assumed and the effects of this curve and its smoothed approximation on the average velocity of propagation of a signal and the elevation angle errors were studied for signals propagated at various ranges and initial elevation angles.

A161 A Study of the Three Dimensional Distribution of the Radio Refractive Index
Bean, B. R.
N.B.S. Report 6042
Feb 59

An analysis of the three dimensional structure of an intense outbreak of continental polar air is presented in terms of the radio refractive index of the atmosphere. Employed for the first time is a reduced index analogous to potential temperature. The reduced value more clearly shows the refractive index structure than the classical methods used heretofore. This new unit is a measure of both atmospheric density and humidity and shows, on a single cross section, the air mass structure and the dynamic mixing of air around the frontal interface.

A162 Subsidence Inversions and Associated Refractive Index in the Pacific High Pressure Cell
Hamilton, Glenn D.
1959 AD 230 566

Subsidence inversions in the Pacific high cell are investigated with respect to the pressure and circulation patterns at the surface, 700 and the 500-mb levels. Numerous parameters, including 500-mb heights, geostrophic verticiy and position relative to the high, were tried for correlation with the height of the inversion, but with inconclusive results. In areas devoid of fronts the initial formation and subsequent behavior of the inversion were found to be very similar regardless of location, providing the upper level circulation pattern was the same. This led to the typing of the upper-air pattern, which appeared to give good results with respect to the height of the inversion.

Refractive index changes in the vertical were generally found to be in proportion to the strength of the inversion.

A163 The Suggested Role of Stratified Elevated Layers in Trans-Horizon Short-Wave Propagation
Bauer, J. R.
Lincoln Laboratory, M.I.T., Tech Rept. 124
Sep 56

Evidence is presented for the existence of very thin substrata within the gross structures of extensive horizontally stratified, elevated, inhomogeneous, dielectric layers between the heights of 1 and 3 km above sea level. Whereas the gross layers are found to have horizontal scales that range from any tens of kilometers to more than 200 km and thicknesses on the order of tens and meters, the observations reported herein indicate the presence of nonturbulent substrata within the gross layers. The horizontal dimensions of the substrata are on the order of kilometers, and their thicknesses range from a few meters to a fraction of a meter. Although the gross layers have refractive index transitions on the order of tens of N-units over thicknesses of tens of meters, the refractive index across the substrata is found to fluctuate vertically on the order of N-units or fractions thereof.

Theoretical estimates of the reflection coefficients of the observed high layers indicate that elevated layers may be capable of supporting the propagation of meter and centimeter waves to distances up to 400 km beyond the horizon. The hypothesis is advanced that reflections from stratified elevated layers play an important role in the propagation of short radio waves to distances well beyond the normal horizon.

A164 Summary of the Dec. 1957, Radar Refraction Meeting
Gerhardt, J. R. (Editor)
Univ. of Texas, EERL Rept 97
Jan 58 AD 154 629

Consideration was given to 4 general subdivisions of the radar refraction problem as it affects Airborne Early Warning operations; these include the measurement or determination, the analysis, the forecasting, and the operational utilization of data concerning the refractive index structure of the atmosphere.

A165 Summary Report Air to Air and Air to Ground Electromagnetic Propagation
Numerous Authors
Cornell Univ. Final Report Part II
Jun 51

A summary of existing knowledge on wave propagation in the atmosphere for radio frequencies above about 30 megacycles with emphasis on air-to-air and air-to-ground propagation is presented in this report. Propagation in standard and non-standard atmospheres are discussed in theory as well as for experiments. Meteorological theory, experiments and equipment is included. Atmospheric absorption and scattering, and the effect of hills, trees, obstacles, etc. are discussed.

A166 A Survey of Contract DA-23-072-ORD-763 Research on Antenna Pointing Errors Resulting from Radio Refraction, Scattering and Reflection
LaGrone, A. H.
Univ. of Texas, EERL Rept 7-13
Mar 58 AD 162 056

This report presents a summary of twelve reports in which various aspects of the propagation error problem in the earth's atmosphere are investigated. Sample refractive index profiles are presented along with the associated pointing angle error and range error for the profile as determined by ray tracing techniques. In addition, attenuation versus frequency curves for the 10 to 100 MCPS range are shown for propagation in the ionosphere. A study of the pointing error produced in an antenna by a second signal being received simultaneously is also reported. The example is for a conically scanning antenna and the second signal is the earth reflected signal.

A167 Survey of Microwave Refractive Index Analysis and Forecasting Techniques
Moyer, J. E.; Gerhardt, J. R.
Univ. of Texas, EERL Rept 6-18
May 57

A survey is conducted of the important techniques of analyzing and forecasting the vertical and lateral distributions of refractive index for radar propagation. Recommendations for further investigation in this field are offered.

A168 Survey of the National Bureau of Standards' Application of Atmospheric Refractivity Measurements to Radio Propagation Studies
Bean, B. R.
N.B.S. Report No. 5007
Aug 56

A brief general review is made of the National Bureau of Standards' application of radio refractivity data to tropospheric radio propagation problems. An appendix lists various groups of radio meteorological data available at the National Bureau of Standards.

A169 Tables for the Statistical Preditions of Radio Ray Bending and Elevation Angle Error using Surface Values of the Refractive Index
Bean, B. R.; Cahoon, B. A.; Thayer, G. D.
N.B.S. Tech Note 44
Mar 60

Radio ray bending, T, and elevation angle error, ϵ, have been calculated for a wide range of meteorological conditions at 13 climatically diverse U. S. Radiosonde stations. The parameters in the observed linear regression equations of T and ϵ upon the surface value of the refractive index are given for heights of 0.1 to 70 kilometers and initial elevation angles of the ray from 0 to 900 milliradians.

A170 Telecommunications Performance Standards
1. Introduction
2. Radio Refractive Index Climatology
Bean, B. R.; Horn, J. D.; Riggs, L. P.
N.B.S. Memo Rept DM-83-30-1
AD 255 332L

This report is the first part of a series of four reports on Radio Meteorological Standards. The report has as its purpose the compilation and analysis of the extensive radio refractive index data available within the Central Radio Propagation Laboratory of the National Bureau of Standards. The variability of the index of refraction during different seasons of the year and climatic regions is examined. The systematic dependence of the index of refraction upon station elevation made it necessary to consider a method of expressing N in terms of an equivalent sea-level value in order to see more clearly actual climatic differences of various parts of the country.

A171 Telecommunications Performance Standards (Tropospheric Systems)
3. Climatology of Ground-Based Radio Ducts
4. Synoptic Radio Meteorology
Bean, B. R.; Horn, J. D.; Riggs, L. P.
N.B.S. Memo Rept PM-83-30-2
Jun 60 AD 255 333L

This is the second part of a series of four reports on Radio Meteorological Standards. An atmospheric duct is defined to occur when geometrical optics indicates that a radio ray leaving the transmitter and passing upward through the atmosphere is sufficiently refracted that it is travelling parallel to the earth's surface. Maximum observed incidence of ducts was determined as 13% in the tropics, 10% in the arctic and 5% in the temperate zone by analysis of three to five years of radiosonde data for a tropical, temperate, and arctic location. Annual maximums are observed in the winter for the arctic and summer for the tropics. The arctic ducts arise from ground based temperature inversions with the ground temperature less than -25° C while the tropic ducts are observed to occur with slight temperature and humidity lapse when the surface temperature is 30° C and greater.

A172 Telecommunications Performance Standards (Tropospheric Systems)
5. Techniques for Computing Bending
6. The Exponential Reference Atmosphere
Bean, B. R.; Horn, J. D.; Riggs, L. P.
N.B.S. Memo Report PM-83-30-3
Jun 60 AD 255 334L

The importance of radio ray bending in radar evaluation and allied types of radio propagation work is discussed. The total angular refraction of the ray-path between two points cannot be evaluated directly without a knowledge of the behavior of the index of refraction as a function of height. As a consequence, many approaches have been developed by persons working in refraction studies. This report describes (a) the limitations to radio ray-tracing, (b) an approximation for high initial elevation angles, (c) the statistical method, (d) the Schulkin method, (e) the 4/3's earth model, (f) the exponential model, (g) the initial gradient correction method, (h) the departure-from-normal method. After a discussion of the various methods, sample calculations are used to illustrate their application.

A173 Telecommunications Performance Standards (Tropospheric Systems)
7. Fading Regions Within the Horizon
8. Attenuation of Microwaves
Bean, B. R.; Horn, J. D.; Riggs, L. P.
N.B.S. Memo Rept. PM 83-30-4
May 61 AD 255 335L

Rudiments of propagation near and within ground-based ducts are considered using ray tracing techniques in order to determine the regions of prolonged fading within the horizon. The meteorological aspects of ground-based ducts are discussed. Then models based on the atmosphere at Washington, D. C.; Swan Island (in the Caribbean Sea); and Fairbanks, Alaska, are used in making fading region calculations which are reported in the form of Tables and Graphs. A sample computation is performed as an aid in locating antennas in regions of fading or regions of non-fading depending upon the specific interests of a particular project.

A174 Terrestrial Radio Waves, Theory of Propagation
Bremmer, H.
Elsevier Publishing Co.
1949

This presents theoretical aspects of tropospheric propagation over a curved earth.

A175 Theory of Characteristic Functions in Problems of Anomalous Propagation
Furry, W. H.
M.I.T. Rad. Lab Report 680
Feb 45

The problem discussed is that of the calculation of field intensity in the diffraction zone. The fundamental expansion theorem is presented in such a way that the height-gain functions appear as normalized characteristic functions of a boundary value problem. The horizontal propagation constants are simply related to the characteristic values.

Of the various methods of calculating characteristic values and functions for any given M-curve, only the phase-integral or "B.K.W." approximation methods are discussed here. The distinction is clearly drawn between the method useful for strongly trapped modes--the Gamow method--and the Eckersley method for untrapped modes. Both methods are described in full detail. Examples of the Eckersley method are given for simple types of M-curve.

Mathematical details of proofs and calculations are given in the Appendices. Appendix III contains a discussion of transitional cases between surface trapping and trapping aloft with graphical presentation of quantities useful in the calculation of such cases.

A176 Third Quarterly Report for Electromagnetic Propagation Study
Solem, R. J.
Signal Corps Engr. Lab Project 3-99-06-106
Jun 58 AD 209 233

A study is made of the probable errors involved in taking meteorological readings with equipment considered practical in the field. The effect of the meteorological equipment accuracies on the calculated index-of-refraction is shown to be the limiting factor in the accuracy of electronic surveying equipment. Results are reported on initial field work employing the XE-1 version of the AN/PPN-13 including comparative operation between conditions employing the auxiliary channel technique and without the channels. A discussion is included of the information expected to be derived from over-water tests to be conducted. Basic information regarding simplified multipath propagation conditions is among the information expected to be derived from these tests.

A177 Three-Centimeter Radio Wave Propagation in a Surface Duct Over the Gulf of Mexico
Smith, H. W.; Straiton, A. W.
Univ. of Texas, EERL-26
Jul 49

In this paper, a measured modified index of refraction profile for a surface duct over the Gulf of Mexico is used to obtain height-gain and height-phase curves for a wave length of 3.2 cm. The measured modified index of refraction profile is expressed in the form of a linear-exponential curve, a linear-inverse-square curve, and a bilinear curve. Each of these curves is analyzed by the phase integral method to determine the height-gain functions. The signal strength and phase difference curves are calculated and presented for comparison with measured curves for horizontal ranges of 12.3, 31.6 and 40.0 miles.

A178 The Tradewind Inversion as a Transoceanic Duct
Katzin, M.; et al
Electromagnetic Research Corp. Report CRC-3030-3
May 59

Radiosonde data for stations in the South Atlantic trade wind belt are analyzed to determine the potentialities of the trade wind inversion as an elevated duct for transoceanic radio transmission. These were supplemented by refractometer soundings made by an aircraft during the latter part of 1958. These records indicate that a duct is present in the majority of the cases. Since it is known that the radiosonde underestimates ducting because of its slow response, it is concluded that a duct is present practically all the time. On the basis of the data analyzed a specific experiment with two aircraft is proposed to test the propagation potentialities of this mechanism. A frequency of around 200 mc is recommended.

A179 Tropospheric Propagation Study Progress Report for 1955
Carr, T.
U. S. Naval Air Missile Test Center TM Rept 102
Jul 56

The purpose of this report is twofold: First, to advise those engaged in tropospheric propagation research that NAMTC has initiated a limited program in this field; and second, to make available the results of soundings made during 1955. These soundings represent a substantial amount of information on a specific area and, as such, will contribute to the growing fund of similar information.

This report includes a description of the University of Texas' microwave refractometer used by this Center.

The uses of refractive index profiles in a study of electromagnetic propagation characteristics are stated; the geography, and general meteorology of the area are discussed; and available equipment and procedures employed are described. Finally, a brief description is given of the salient points of some of the soundings along with photographically reduced copies of tracings of the actual curves obtained.

A180 Tropospheric Propagation Study Progress Report for 1956
Carr, T.; Appel, J.
U. S. Naval Air Missile Test Center TM Rept 106
May 57

This work is reported in two parts. Part I considers Microwave Propagation as Observed Varying Meteorological Conditions, and Part II considers the Effect of the Santa Barbara Channel Islands on Superrefractive Layers. Appendix material includes an explanation of a refractive-index analog computer for use with radiosonde data, and a description of a method of calibrating the microwave refractometer during flight.

A181 Tropospheric Propagation Study Progress Report for 1957
Carr, T. R.; Wright, S. F.
Point Mugu Calif, NAMTC TM 106
Jun 58

The results of propagation flights conducted during the first quarter of 1957 are reported. The effects of an isolated island on refractive layers are discussed. Brief comments are made relative to refractive-index measurements taken at altitudes above 10,000 feet and to diurnal variations in refractive layers. A refractive-index climatological study is described, and the results of a laboratory check on the microwave refractometers used in the program are presented. The general test plan of the NAMTC tropospheric microwave propagation program is also presented. Appendix material includes NAMTC's presentation at the Office of Naval Research Radar Refraction Symposium in February, 1957.

A182 Tropospheric Propagation Study Progress Report for 1958
Chegwidden, R. E.; Wright, S. F.
Point Mugu Calif, NAMTC TM 60-15
May 60 AD 237-801

A study to determine the effect of refractive layers on microwave propagation and to investigate the nature and cause of these refractive layers is discussed in four parts. The first discusses the significance of weather conditions prevailing at the time refractive index soundings are made. The second is an annual climatological study to show yearly trends in the occurrence of super refractive layers and monthly trends in relative strength, height, and thickness of such layers. The third is an effort to determine the effect of isolated land mass on superrefractive layers. The last section discusses the effect of refractive layers on the propagation of S-Band Radar Signals.

A183 Tropospheric Refraction Effects on Height-Finding Radars
Bailin, B.; Colin, L.
Rome Air Development Center Tech Note 59-1
Feb 59 AD 208-284

Radar systems of today are simultaneously achieving increased range and accuracy capabilities. Requirements for more accurate corrections for atmospheric refraction are desired than is provided for by the four-thirds earth's radius approximation. The prime purpose of this report is to survey the state-of-the-art of refraction problems and specific correction procedures are indicated as related to height finding radars. A number of atmospheric models are presented. However, the exponential atmospheric model has been shown to be fairly representative of the index of refraction profile in the average case. Deviation from the average case are also presented.

It is indicated that the range error and elevation angle errors both contribute to the computation of the over all height error resulting from atmospheric refraction of radio waves tracking a target within the troposphere. However, the role played by the elevation angle error dominates the contribution.

A184 Tropospheric Refractive Index Measurements in Eastern Colorado During August 1954
Hines, C. A.; Tobias, J. J.
Wright Air Development Center TM 55-482
Nov 55 AD 89 093

Refractive-index data are presented which reveal the structure of the troposphere during a two-week period over the terrain of eastern Colorado just East of the Rocky Mountains. In four of the six flights which were conducted, transition layers and turbulent regions were present. Transition layers varied in thickness from 100 ft. with the base at 11,000 ft. to 700 ft. with the base at 13,500 ft. The layers had lapse rates ranging from -53 to +3 N units/1000 ft. Turbulent regions ranged from 600 to 8000 ft. in thickness, with the maximum change in refractive index ranging from 8 N units in a 150-ft. change in altitude to 11 N units in a 100 ft. change in altitude. More fluctuations occurred at lower altitudes in regions where transition layers occurred, with fluctuation maximums (1) ranging from a 4 N unit to a 1 N unit change in 0.2 sec. or a 50 ft. horizontal displacement, and (2) occurring at altitudes from 4000 to 15,000 ft.

A185 Tropospheric Variations of Refractive Index of Microwave Frequencies
Campen, C. F.Jr., Cole, A. E.
A. F. Cambridge Res. Center, Bedford, Mass.
Oct. 55 AD 85 042

The effect of gross variations in tropospheric refractive index on the accuracy of radio guidance systems for high altitude vehicles is discussed. Refractive index profiles prepared from radiosonde observations taken for three summer and three winter days at stations in different geographical locations in North America and representing various types of air masses are compared with a Standard Index of Refraction curve derived from the ICAD Standard Atmosphere. Variations of the index at the ground, at 20 kilo feet, the average of the index from the ground to 20 kilo feet and the differences between these and the Standard Index are given. It was found that the index varied by 135 N units at the ground, by 21 N units at 20 kilo feet and that the average index from the ground to 25 kilofeet varied by 35 N units. When categorized by air mass type, by location or by time intervals, variations within any of these categories were much smaller. Differences between the computed indices and the Standard Index ranged from +71 to -64 N units at the ground, from +17 to -4 N units at 20 kilo feet. The differences between the averages of the index from the ground to 25 kilo feet and the average of the Standard Index ranged from +23 to -12 N units. Correlation of these average index data with surface index data was found to be very good. A correlation coefficient of 0.98 was obtained. For the scattergram, a regression curve was drawn which showed a standard estimate of error of only 5 N units. Sample calculations of refractive errors were made which show use of the index data for correction of these errors.

A186 Tropospheric Weather Factors Likely to Affect Superrefraction of VHF-SHF Radio Propagation as Applied to the Tropical Western Pacific
Smith, E. D.; and Fletcher R. D.
Weather Bureau, Washington, D. C., Rept. No. RP-1
Jul 44 AD 65 589

The meteorological characteristics of the Tropical Western Pacific are presented in this preliminary report as a guide to the radar meteorologist engaged in forecasting the atmospherically modified index of refraction or M curve. As an aid in making such forecasts, the relations between the effects of atmospheric phenomena and radar and VHF-SHF radio wave propagation are presented in terms of standard and non-standard atmospheres and M curves. Methods for computing the M curve from aerological low-level sounding data are presented. The influence of changes in temperature and mixing ratio with height on the shape of the M curve is discussed for various cases of non-trapping and trapping of radiated energy in an atmospheric duct.

A187 UHF Propagation Study
Latour, M. H.
Florida Univ., Gainsville, Fla.; Final Rept. Vol.1
Sep 59 AD 228 623

Results of a UHF experimental trans-horizon propagation study are presented. The propagation path of 300 was entirely over sea. Received pulse signals at 1260 MC were sorted into 30 levels approximately one db apart and amplitude distribution recorded in real time. Summer time signals were found to be generally higher than those received during the winter. Any diurnal variations were masked by other factors which produced greater signal variations. The signal levels appeared to be related to the absolute value of the surface refractive index of the atmosphere. Refractometer data indicated greater fluctuation of atmospheric refractivity with height during the summer months. The short term variation of the signal appeared to be Rayleigh distributed except during periods of super-refraction. The fluctuation rate varies inversely with signal amplitude, with higher rates associated with low signal periods. Evidence of multipath propagation was observed frequently. Many cases of extreme delays were obviously caused by the ionized paths of lightning discharges. Other cases are suspected of being caused by forward scatter from rain.

A188 The Use of Potential Refractive Index in Synoptic-Scale Radio Meteorology
Jehn, K. H.
Univ. of Texas, EERL Rept. 6-29
Sep 59 See Periodical P186

The concept of potential refractive index is examined in the light of earlier work and of the present emphasis on synoptic-scale radio meteorology. A new potential refractive index is defined and illustrated. It is concluded that the new parameter has operational utility in long range microwave radio and radar transmission, as well as in refractive index mapping.

A189 Variability of Microwave Refractive Index at the Surface and at 850 MBs over Canada and Alaska in April and October
Jehn, K.H.
Univ. of Texas, EERL Rept. 7-17
Aug 58

This report presents distributions of microwave refractive index at the surface and 850 millibar levels for 14 selected stations in Canada and Alaska for the months of April and October for a minimum period of 5 years. Mean values of refractive index and standard deviations are tabulated for all stations for each of the months. In addition, the mean gradient of refractive index from the surface to 850 millibars is shown, along with the standard deviation of this quantity.

A190 VHF Propagation Measurements in the Rocky Mountain Region
Kirby, R. S.; Dougherty, T. H.; McQuate, P. L.
N.B.S. Report 3564
Jan 56

Mobile measurements of VHF propagation over various irregular terrain paths have been made by the National Bureau of Standards in the Colorado Rocky Mountain region in an effort to evaluate terrain effects upon broadcast and point to point communications at very high frequencies. Mobile measurements of the varying path transmission loss were obtained in a continuous manner while driving along selected routes with a mobile field strength recording unit, which consists of a modified house trailer equipped with a telescoping mast and pulled by a pick-up truck. The paths used ranged from relatively smooth to very rough.

The results of the measurements are considered in the light of current irregular terrain theory. The correlation of sector median transmission loss for different frequencies over irregular terrain tends to be high when the paths are nearly the same, becoming significantly less when the paths diverge. This would indicate that the frequency selectivity of an irregular terrain path is small.

A191 X-Band Phase Front Measurements in Arizona During April 1946
Hamlin, E. W.; Gordon, W. E.; Lagrone, A. H.
Univ. of Texas, EERL Rept. 6
Feb 47

The phase difference between two points, approximately one hundred feet above the ground, separated vertically by ten feet, and signal strength at each point were measured on a twenty-seven mile desert path for transmitter heights varying from ground level up to one hundred and ninety feet. Modified index of refraction versus height was measured at the midpoint of the transmission path. Analysis of this data and numerous interesting conclusions constitute the major part of the report.

SECTION V

NON ABSTRACTED REPORTS

N1 Air to Air Tropospheric Propagation Over Water
Unknown author
USAF, WADC Tech. Rept. No. 52-135
Jun 52

N2 An Analysis of Airborne Measuremments of Tropospheric Index of Refraction Fluctuations.
Edmonds, F. N.
Statistical Methods of Radio Wave Propagation, Pregamon Press
197-211
1960

N3 Atmospheric Bending of Radio Waves
Bean, B. R.
Crongres International Sur La Propagation Des Ordes Radio-Electriqism Liege, Oct. 6-11 Nesume Des Communications, 3
Oct 58

N4 Atmospheric Effects on Ground-To-Air Microwave Radio Propagation Supplement No. 1
Taylor, P. B.
WADC Wright Patterson AFB
Jun 57

N5 Atmsopheric Refraction - A Preliminary Quantitative Investigation
Anderson, L. J.
USN Radio & Sound Lab. Rept. No. WP-17
Dec 44

N6 Atmospheric Refraction Under the Condition of a Radiation Inversion
Anderson, L. J., et. al.
USN Radio & Sound Lab. Rept. WP-19

N7 Average Radio Ray Refraction in the Lower Atmosphere
Schulkin, M.
NBS Central Radio Propagation Lab. Rept. CRPL-2-2
Aug 47

N8 Bibliography of Reports on Tropospheric Propagation
Unknown
Central Radio Propagation Rept. CRPL-2-3
Jul 48

N9 Calculation for Atmsopheric Refractive Index
Anderson, L. J.
USN Electronic Lab. Rept. 279, San Diego
Mar 52

N10 The Calculation of Refractive Corrections for Ground-To-Air Observations
Michael, J. H.
NASA Tech. Pub. No. 24 (N-84118)6
Jul 60

N11 Catalogue of Microwave Refractive Index Recordings on File at the Electrical Engr. Res. Lab.
Unknown
Rept. No. 6-16 EERL Univ. of Texas
Aug 56

N12 Characteristics of Point-To-Point Tropospheric Propagation and Siting Considerations
Kirby, R. S., Rice, P. L., Maloney, L. J.
U.S. Dept. of Commerce, NBS
Oct 61

N13 Check List of References to Literature on Tropospheric Propagation of UHF, VHF and SHF Radio Waves (1918-1957)
Nupen, W., Thuronyi, G.
NBS Rept. No. 6001
Aug 58

N14 Check List of References to Literature on Tropospheric Propagation of UHF, VHF and SHF Radio Waves (1929-1959)
Nupen, W.
NBS Rept. No. 6005
Jul 59

N15 Cheyenne Mountain Tropospheric Propagation Experiments
Barsis, A. P. et. al.
US NBS circ554:1-39 pa30c Supt. of Doc. 155

N16 Comparison of Predictions of Vector Model of Microwave Reflection from the Ocean with Experimental Results
Beard, C. I., Brooks, F. E. Jr.
Appl. Phys. Lab. John Hopkins Univ. Rept. No. CF 2526
Jun 56

N17 Computing the Index of Refraction of the Atmosphere
Cowan, L. W.
Air Defense Command Forcast Center, 3rd Weather Group Tech. Paper No. 1 Colorado Springs, Colo.
May 52 AD 58 892

N18 The Constants of the Equation for the Refractive Index of Air
Smith, Ernest K. Jr. (NBS, Wash)
IRE/PGAP: URSI-IRE Meeting
Apr 52

N19 Correction of Radar Data for Refraction Errors
Barbery, T. B.
WSSA Tech. Rept. 22
Dec 54

N20 The Correlation of Tropospheric Radio Propagation with Meteorological Observations in the Central Texas Area
Metcalf, D. F.
U. of Texas EERL 1-17

N21 CRPL Exponential Reference Atmosphere
Bean, B. R.; Thayer, G. D.
NBS Monograph 4
Oct 54

N22 The Determination of Charge Density in the Ionosphere by Radio Doppler Techniques
Berning, W. W.
Rocket Exploration of the Upper Atmosphere, Pergamon Press
1954

N23 The Diffraction and Refraction of Pulses
Papadopoulos, V. M
Brown Univ.
May 59

N24 The Direct Measurement of the Variations in the Index of Refraction of Atmospheric Air at Microwave Frequencies
Gerhardt and Crain
EERL Rept No. 38 U. of Texas
Apr 50

N25 Directly Recorded Tropospheric Refractive Index Fluctuations and Profiles
Crain, C. M. U. of Texas
IRE/PGAP: URSI-IRE Meeting p. 79
Apr 52

N26 The Effect of Atmospheric Refraction on the Evaluation of Upper Air Winds by Radio Direction and Position Findings
Eckstein, A.
Army Sig. Corps., Evan Signal Lab. Tech. Memo TM-GE-12
1945

N27 The Effect of Atmospheric Refraction on the Propagation of Radio Waves
Stickland, A. C.
Dept. of Sc. & Ind. Res. - Radio Res. Board/S10
1943

N28 The Effect of Atmospheric Refraction on Short Radio Waves
Freehafer, J. E.
Radiation Lab. Rept. No. 447 MIT
Nov 43

N29 The Effect of Meteorological Factors upon the Velocity of Radio Waves
Warner, J.
Commonwealth Scientific & Industrial Res. Organ.
Div. of Radiophysics
Aug 49

N30 Effects of Atmospheric Conditions on Precision Tracking Radar
Boyd, J. E.
Res. & Dev. Board, Comm. on Electronics
Dec 49

N31 Effects of Topography and Refractive Index on Low-Angle 3-CM Radio Waves
Tomlinson, H. T.
U. Of Texas EE Disertation
Aug 58

N32 Electromagnetic Wave Propagation in a Medium with Variable Dielectric Constant $1+kr^{-1}$
Flammer & Carson
Stanford Res. Institute Tech. Rept.
Jan 58

N33 Equation Designed to Correct Radar Range and Angle Information for Errors Caused by Atmospheric Refraction
Temple, E.
Rept. No. TM-1072 RCA Electronics & Controls Div.
Apr 60

N34 A First Order Approximation Correction for Refraction Errors in Radar Range Measurments
Dixon, H. M.
WSSA Tech. Rept. 18F
Aug 57

N35 A Further Study of the Modified Index-of-Refraction Over the Gulf of Mexico as Determined from Radio Data
Straiton, A. W., Lagrone, A. H., Landgren, G. F.
U. of Texas EERL-35
Nov 49

N36 Gradient of Refractive Modulus in Homogeneous Air, Potential Modulus
Katz, I.
Propagation of Short Radio Waves by D. E. Kerr

N37 A Graphical Method of Interperting Refractive Index Profiles in Terms of Air-to-Air Coverage
Arnold, G.
Lockheed Aircraft Corp. Burbank M.O.R.D.
1956

N38 Hourly Correlation of Radio Path Lengths and Surface Refractivity Index from Maui
Thompson, M. C., Freethey, F. E.
NBS Rept. 5579
Jun 58

N39 Improvements in Refraction Correction and Height Accurate for Radar Height Finders
Bruck, G., Schipper, R. J., Kine, F. W.
AVCO Mfg. Corp., Crosley Div.
Jan 58

N40 Instantaneous Electronic Ray Tracing Computer for the Solution of Electromagnetic Propagation Problems
Springer, P., Rawhouser, R.
Reprint from Electromagnetic Wave Propagation, Academic Press

N41 Ionospheric Refraction and Faraday Effect at Frequencies above 100Mc
Weisbrod, S., Heritage, J. L.
Mar 56 AD 138 621

N42 The Layered Atmosphere & Scatter Propagation
Ament, W. S., Ringwalt, D. L.
Presented at URSI Spring meeting, Wash. D.C. (unpublished)
Apr 56

N43 Low Level Atmospheric Ducts
Jones, R. F.
London, 163(4147):639
Apr 49

N44 Low Level Meteorological Soundings and Radar Correlations for the Panama Canal Zone
Fitzsimmons, K. E. et. al.
Wash. State College, Dept. of Phys. Rept. No. 6 NDRC Proj. No. PDRC-647
Jun 44

N45 Measurements & Analyses of Index of Refraction of the Atmosphere
Gerhardt, J. R. U. of Texas
EERL 6-19
Mar 57

N46 Measurements of Temperature & Humidity in the Lowest 1000 ft. of the Atmosphere over the Massachusetts Bay
Craig, R. A.
Papers in Physical Oceanography and Meteorology Vol. X No. 1

N47 Meteorological Analysis of Angle-of-Arrival Measurements; Summary Technical Report of the Committee on Propagation.
Lukes, G. D.
NDRC Vol. 2 p. 207
1946

N48 Meteorological Analysis of the Propagation of Microwaves with an Application to Angle-of-Arrival Measurements
Lukes, G. D.
Evans Signal Lab. Tech. Memo No. TM-GE-10
May 45

N49 Meteorological Factors & Their Effects on Microwave Propagation
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